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Report RM-121**

Vegetation and Soils of an Alpine Range in the Absaroka Mountains, Wyoming

John F. Thilenius and Dixie R. Smith

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Abstract

Alpine vegetation on Carter Mountain in the Absaroka Range of northwestern Wyoming was classified into eight community types. Community type differences are due mainly to shifts in the standing crop and constancy of a few species. Floristic differences among community-types are not marked, and very few species are confined to a single community type. Soils associated with each community type were classified to soil subgroup level. No consistent relationships were found between the vegetation and soil classifications. Exposure to prevailing wind, elevation, soil particle size distribution, available water content, and snow accumulation were statistically significant environmental factors determining community type distribution.

Acknowledgements

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Contents

Page

INTRODUCTION 1
STUDY AREA 1
METHODS 2
  FIELD PROCEDURES 2
  DATA ANALYSIS 2
SOIL CLASSIFICATION AND MORPHOLOGY 3
VEGETATION 3
  FLORISTICS AND PRODUCTION 3
  PHYTOSOCIOLOGY 3
    Ordination 3
    Classification 7
VEGETATION-SOIL RELATIONSHIPS 9
ENVIRONMENTAL RELATIONSHIPS 9
LITERATURE CITED 10
APPENDIX 1. Morphology of soils of study area 12
APPENDIX 2. Average standing crop (SC), percentage composition by weight (CW) and percentage constancy for taxa in eight community types of study area 14
APPENDIX 3. Major habitat features and soil properties of eight alpine community-types of study area 16
APPENDIX 4. Scientific and common names of plants 17

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INTRODUCTION

Of the five major mountain ranges in northwestern Wyoming (Absaroka, Beartooth, Gros Ventre, Teton, Wind River), only the Absaroka Range is of volcanic origin. The highly dissected Absaroka Plateau covers an area approximately 80 by 130 km, much of which exceeds 3000 m elevation. Consequently, alpine vegetation is widely distributed. Access to the alpine zone is limited by the steep and rugged terrain below it and by the loosely consolidated, easily disturbed volcanic material which makes travel difficult and sometimes dangerous. Large portions of the mountains are in wilderness, which further limits easy access.

Only a very limited amount of scientific information is available on the alpine vegetation of the Absaroka Range, although the alpine vegetation and soils of the nonvolcanic Beartooth Plateau immediately to the north have been studied (Johnson and Billings 1962, Nimlos and McConnell 1962).

Strasia et al. (1970) studied the influence of grazing by domestic sheep on the alpine vegetation at Carter Mountain on the eastern edge of the Absaroka Range. They provided some information on taxa composition and coverage, and on selection and utilization of alpine plants as forage by sheep. In general, their work was oriented toward range management rather than ecology. However, the study indicated a need for more detailed information on the vegetation and soils of Carter Mountain and in, part, was responsible for the initiation of this study.

Study objectives were: (1) to determine taxa composition and aboveground production of the alpine vegetation on Carter Mountain; (2) to develop a phytosociological classification of the vegetation; (3) to classify the alpine soils according to the current system of soil taxonomy; (4) to examine the relationship between the vegetation and soil classifications; (5) to determine the environmental factors that may influence plant distribution.

In addition to the scientific aspects, there was a practical need for such information. The alpine zone on Carter Mountain is almost entirely within the Shoshone National Forest. It provides summer and early fall range for domestic sheep and for many kinds of wildlife. Classification of the vegetation and soils provides a framework for land use planning. It is essential for proper, long-term, range management on this Federally controlled range.

STUDY AREA

Carter Mountain is a long (ca. 32 km) northeast-southwest trending ridge on the eastern edge of the Absaroka Range. Along the northwestern side, it is an almost unbroken line of vertical cliffs and steep talus slopes of rounded, loose rocks. The southeastern side of the mountain is much less steep and rugged. The horizontal distance from the crest of the main ridge to the lower edge of the alpine zone varies from 2 to 5 km.

The alpine zone on Carter Mountain begins at about 3000 m elevation and extends to the crest (ca. 3750 m). Isolated groves of *Picea engelmannii*[2] and *Abies lasiocarpa* and some scattered *Pinus flexilis*, are present on the southeastern slope. These groves are composed of erect trees and are confined to steep mesic slopes along watercourses.

On ridges and other convex topography interspersed between the *Picea-Abies* groves is a shrub-grass vegetation where *Artemisia tridentata* dominates the shrub stratum. In places, this high elevation extension of the Great Basin sagebrush-type abuts almost directly upon true alpine vegetation. *Hesperochloa kingii* is a conspicuous member of the herb stratum in this vegetation. Usually, the transition between alpine and Great Basin shrub extends over 150 to 200 m of elevation.

The rim and the talus slopes along the northwestern side of the mountain abruptly delineate the boundary between the alpine zone and coniferous subalpine forest below. There is an almost complete absence of the coniferous krummholz that often characterizes the alpine-subalpine transition in other areas of the Rocky Mountains.

The volcanic substrate of Carter Mountain is of late Eocene and Oligocene origin. The base of the mountain is basalt and breccia. The upper part has been identified only as basic breccia on the Wyoming geologic map (Love et al. 1955). This breccia is a mass of cinders, ash, tuff, basalt, pumice, conglomerate, and other pyroclastic material.

The soils on Carter Mountain are derived from this heterogenous mixture of volcanic materials. Below the zone of maximum weathering the rock fragments are a partially cemented mass; within the upper 1–3 m the rock is more fragmented, and cementation into a continuous body is weak or absent. This relatively unconsolidated rock mass is considered to be a fragmental substratum (IIC horizon) rather than a lithic contact.

Examples of both active and inactive cryopedogenic processes can be observed. The fragmented substratum promotes good to excessive drainage conditions, and indications of restricted drainage such as gleyed or mottled subsoils were not present.

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[2] Taxa identifications were checked by the Rocky Mountain Herbarium, University of Wyoming, Laramie. Voucher specimens are on file there and at the Forest, Range and Watershed Laboratory, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Laramie, Wyo.

There are no long-term weather records from the study area. From observations made during the study, the general climate is believed to be similar to that of other alpine areas in the Rocky Mountain region. Winds are predominantly northwesterly and strong (20–30 km/h) throughout the year. Summer temperature data that might be extrapolated to Carter Mountain were collected by Johnson and Billings (1962) on the Beartooth Plateau about 80 km to the north. There, the mean July air temperature ranged from 7° to −9° C.

The precipitation map of the state of Wyoming (Wyoming Water Planning Program, n.d.) indicates Carter Mountain lies between the 30- and 50-cm isohytes. Actual precipitation may vary greatly from that indicated on the maps. Summer thundershowers are common, with precipitation often in the form of hail or snow. Relatively heavy snowfall may occur in late August or early September. Aerial photographs taken in winter show ridges and other sites exposed to the wind to be free of snow, while deep accumulations of snow occur in watercourses, on lee slopes, and in local sheltered areas. This snow may remain until late July or early August.

The study area had been grazed by domestic sheep for many years. Wapiti (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), and somewhat suprisingly in the alpine zone, pronghorn antelope (*Antilocapra americana*) were often seen during the study. Bighorn sheep (*Ovis canadensis*) were also present on Carter Mountain. Small herbivorous mammals included pika (*Pika pika*) and marmot (*Marmota flaviventris*). Pocket gophers (*Thomomys* spp.), voles (*Microtus* spp.), and other microtines were not common.

Except for activities associated with domestic sheep grazing, human influence has been limited. The area is traversed by a road only barely passable by four-wheel drive vehicles in late summer and early fall. Hunters use the area in the fall, but summer recreational use is nonexistent. Oil exploration had been carried out on Carter Mountain in the past, but there had been no activity for several years prior to sampling.

METHODS

FIELD PROCEDURES

The study sites were at the headwaters of Little Rose Creek, Rose Creek, and Meeteetse Creek in Sections 7, 8, 17, 18, 19, 20; T49N; R103W; 6th Principal Meridian, Wyoming. Within the study area 29 randomly located stands were sampled during the period July 18 to August 3, 1969. Each stand was 5 by 5 m. All of the sampled stands had been grazed by domestic sheep for many years prior to sampling.

Within a stand, a systematically located sample of 20 quadrats, each 0.3 by 0.3 m, was used to estimate aboveground standing crop. Aboveground herbage of vascular plants was clipped to a 1-cm stubble height, separated by taxon, and placed in plastic bags. Oven-dry weights (24 h at 105° C) were determined to the nearest 0.1 g.

A soil pedon in each stand was described to Soil Conservation Service standards (USDA Soil Conservation Service 1975). Samples of at least 100 g of soil were collected from each horizon for laboratory analyses. The analytical techniques and standards given in *Soil Taxonomy* (USDA Soil Conservation Service 1975) were followed.

The following site features were recorded: elevation (meters); slope aspect (degrees from true North); slope gradient (percent); position on slope from nearest ridgeline (top, upper 1/3, mid 1/3, lower 1/3, base); estimated depth and duration of snow accumulation; exposure to wind (lee, windward).

DATA ANALYSIS

A correlation matrix was made from the taxa that averaged at least 0.9 g/m² of aboveground standing crop. The 20 taxa with the highest variance or a significant ($p = 0.1$) covariance were selected for principal component analysis (van Groenewoud 1965). Principal components were derived from a Q-type analysis, which expresses interstand relationships.

The first three principal components were used as the basis for a three-dimensional ordination of the stands. Stands were ordinated in three-dimensional space by graphical plotting and were grouped on the basis of their proximity in the three-dimensional space. The groups were defined primarily on taxa composition and aboveground standing crop. Average aboveground standing crop was calculated for each taxon by using the total number of stands within a group as the divisor. Soil and site attributes were summarized in the same manner.

Sorensen's coefficient (Sorensen 1948) was used to determine the similarity of the groups of stands established by the ordination. The initial matrix of similarity was based on the standing crop of the 20 taxa used in the ordination. The weighted pair-group method (Sokal and Sneath 1963) was used to classify the stand groups and to show intergroup relationships. To test the adequacy of the use of only 20 taxa to establish stand groups, the similarity and cluster analyses were repeated with all of the 60 taxa encountered in sampling.

Soil scientists of the Soil Conservation Service classified the soils to the Soil Subgroup level by the methods described in *Soil Taxonomy* (USDA Soil Conservation Service 1975).

The method of van Groenewoud (1965) was used to examine the first three principal components in an ecological context. Site and soil attributes were individually plotted against the corresponding eigenvalue of the stand on each of the first three principal components. The resulting scatter diagram was visually examined for an evident relationship. If this was found a line was fitted to the scatter of points. Simple correlation coefficients were calculated when a straight-line relationship was present.

SOIL CLASSIFICATION AND MORPHOLOGY

Although no data were available on soil temperature from Carter Mountain, it was assumed the temperature regime was similar to other alpine sites in the Rocky Mountain region. The soils described were assumed cold enough to be placed in the "Cryo" great group soil category (soils with a mean annual temperature in the range 0–8° C) and in the Pergelic soil subgroup (mean annual soil temperature 0° C).

Data on bulk density could only be estimated, because of the large amount of coarse fragments present and the lack of discrete peds. Consequently, only the physical and chemical attributes of cation exchange capacity, exchange acidity, water retention at 15 bars, and clay content were used to substantiate placement of some of the pedons in an Andic subgroup.

The pedons from the 29 stands represented three soil orders: Entisols—soils with little or no evidence of pedogenic development; Inceptisols—soils with altered horizons that have lost bases and aluminum, but that retain some weatherable minerals; Mollisols—soils with dark-colored, base-rich surface horizons, and subsurface horizons with variable degrees of pedogenic development.

The three soil orders were further subdivided into seven soil subgroups. Brief description of these follow. More complete information on the morphology of these subgroups is given in appendix 1.

Pergelic Cryorthent, fragmental, mixed (2 of 29 pedons).—These were shallow soils with little pedogenic development. An ochric epipedon (a thin, light-colored surface horizon, low in organic matter) rested directly on a fragmental substratum (IIC horizon).

Pergelic Cryochrept, coarse-loamy over fragmental, mixed (2 of 29 pedons).—These soils had some pedogenic development, but without mineral accumulation or extreme weathering. A cambic horizon, (an altered, non-illuvial, subsoil horizon with texture finer than loamy fine sand) occurred immediately below the diagnostic ochric epipedon.

Andic Entic Pergelic Cryumbrept, loamy-skeletal over fragmental, mixed (6 of 29 pedons).—These soils had an umbric epipedon (a dark-colored surface horizon with base saturation below 50%) resting directly on a fragmental substratum. The term Entic indicates poor pedogenic development; Andic indicates 60% or more (by weight) of the soil is vitric volcanic ash, or other pyroclastic materials.

Andic Pergelic Cryochrept, loamy-skeletal over fragmental, mixed (1 of 29 pedons).—This subgroup was similar to the Pergelic Cryochrept subgroup except for a low, 15-bar clay-to-water retention ratio, which placed it in the Andic subgroup.

Andic Pergelic Cryumbrept (8 of 29 pedons).—These soils had well-developed, often subdivided cambic horizons underlying relatively thick umbric epipedons. The surface horizon rested directly on a fragmental substratum (IIC horizon).

Andic Pergelic Cryoboroll, fragmental, mixed (3 of 29 pedons).—This subgroup was characterized by the presence of a shallow mollic epipedon resting directly on a fragmental substratum. A mollic epipedon is a relatively thick, dark-colored, mineral surface horizon with base saturation higher than 50% and a relatively high organic carbon content. Two of the pedons had mollic epipedons less than the required 18 cm thickness, but as all other requirements were met they were considered to be true mollic epipedons.

Andic Pergelic Cryoboroll, loamy-skeletal, mixed (7 of 29 pedons).—In this subgroup all mollic epipedons met the required 18 cm thickness. Cambic horizons were present in six of the seven pedons.

VEGETATION

FLORISTICS AND PRODUCTION

Sixty vascular plant taxa were found on the 29 sample stands (appendix 2). Forb taxa were much more common than gramineous taxa. Two categories of forbs were present: erect forbs (38 taxa) and cushion plant forbs (8 taxa). The prostrate shrub *Salix recticulata* was the only woody plant present. It was included in the erect forb category. Grasses (9 taxa) were more common than graminoids (sedges and woodrush—5 taxa). Lichens and bryoids were not sampled.

As is generally the rule in alpine vegetation, while many taxa were present, most of the aboveground standing crop was produced by relatively few taxa. Nineteen taxa (8 erect forbs, 7 cushion plant forbs, 2 grasses, and 2 sedges) produced 84% of the average total standing crop of 107.6 g/m^2.

Four genera produced 54% of the average total standing crop. The most productive genus was *Trifolium* (3 species), which produced 18% of the average total standing crop. One species (*Geum rossii*) produced 15% of the average total standing crop. This species is widely distributed in the alpine zone of the North American cordillera. On the study area it was the most abundant and conspicuous plant throughout the growing season. Other genera that produced a large portion of aboveground standing crop were *Phlox* 12% and *Poa* 9%.

PHYTOSOCIOLOGY

Ordination

The first three principal components accounted for 32%, 17%, and 13%, respectively, of the total variation in taxa composition and standing crop biomass; the other 26 components accounted for the remaining 38% of the variation (table 1). Three-dimensional or-

Table 1.—Eigenvectors and eigenvalues of the first three principal component axes of the 29-stand matrix.

Stand	Axes 1	2	3
	eigenvectors for plots		
16	-0.15527	-0.30227	-0.18831
19	0.05138	-0.40368	0.00316
15	0.01433	-0.38171	0.09341
14	-0.03321	-0.25253	0.12229
30	0.05535	-0.28129	-0.12325
40	0.04995	-0.24710	-0.25467
20	0.02113	-0.20075	-0.11274
18	0.06138	-0.25967	-0.13644
11	0.00095	-0.00841	0.00841
10	0.00066	-0.08534	-0.23043
28	0.07116	-0.05542	-0.36007
29	0.09450	-0.00754	-0.39689
36	0.25856	-0.12950	0.14946
23	0.18987	-0.18725	0.17393
12	0.11114	-0.18612	0.27301
17	0.24502	-0.09234	0.23897
21	0.24611	-0.13048	-0.20819
22	0.26222	-0.01621	-0.24893
38	0.22036	0.03545	-0.17735
27	0.22841	0.11560	-0.17014
31	0.14386	0.09704	-0.10694
35	0.28779	-0.02856	-0.05186
25	0.29424	0.02130	0.20941
38	0.22036	0.03545	-0.17735
26	0.30005	0.10045	-0.01125
37	0.28183	0.16145	0.07567
39	0.23628	0.17615	0.09722
24	0.20228	0.19876	0.11376
32	0.06321	0.08442	0.14539
Eigenvalues	9.31255	5.03224	3.52761
Cumulative variation (%)	32.11	49.48	61.63

dination segregated the 29 stands into eight groups (fig. 1). The third vector was particularly effective in separating stands that appeared to be in close proximity on the two-dimensional, vector 1:vector 2 ordination plane. Six multiple-stand groups, one two-stand group, and one single-stand group were delimited.

Eleven of the 60 taxa had relatively high average aboveground standing crop and 100% constancy in one or more groups; they will be referred to as characteristic taxa. "Characteristic" has been used in preference to "dominant" because it does not imply these taxa exert any control over the other taxa present. Nine characteristic taxa had been used in the ordination: *Geum rossii, Poa* spp., *Trifolium dasyphyllum, T. nanum, T. parryi, Phlox pulvinata, P. multiflora, Lupinus greenii, and Artemisia scopulorum.* Two taxa, *Antennaria rosea,* and *Erigeron compositus,* which had not been used in the ordination, were used as characteristic taxa in two groups because of high standing crop and constancy. None of the characteristic taxa was confined to a single group, and many were present at low constancy or standing crop in all groups.

The eight classes were defined by the following combinations of characteristic taxa:

Characteristic taxa	**Acronym**
Geum rossii-Trifolium parryi	Gero-Trpa
Geum rossii-Trifolium nanum	Gero-Trna
Trifolium dasyphyllum-Geum rossii	Trda-Gero
Lupinus greenii-Poa spp.	Lugr-Poa
Phlox pulvinata-Trifolium dasyphyllum	Phpu-Trda
Antennaria rosea-Artemisia scopulorum	Anro-Arsc
Phlox multiflora-Trifolium nanum	Phmu-Trna
Erigeron compositus-Poa spp.	Erco-Poa

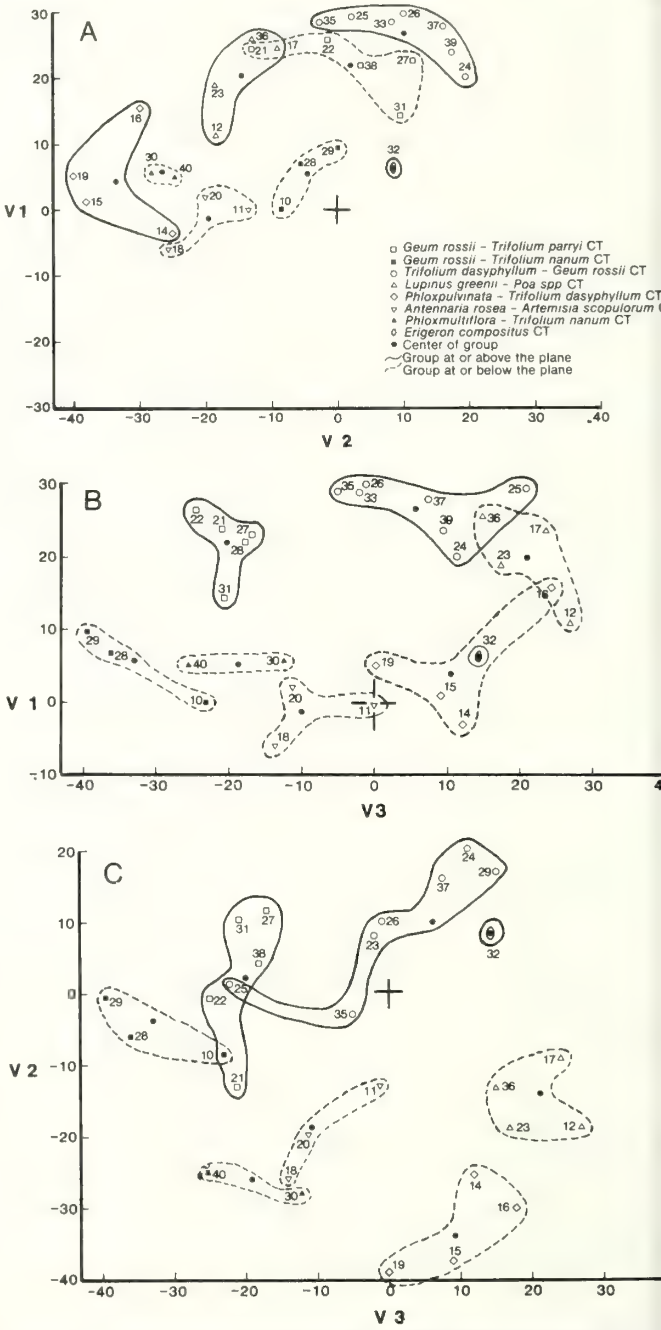

Figure 1.—Ordination of 29 stands of alpine vegetation on (A) th first (V1) and second (V2) principal components; (B) the first (V and third (V3) principal components; (C) the second (V2) an third (V3) principal components.

The first taxon listed produced the greatest average aboveground standing crop. *Poa* spp. represents at least three different species—*P. alpina, P. pattersonii,* and *P. rupicola.* These usually were present without flowers and could not be identified separately. Consequently, it was overrepresented in comparison to the other characteristic taxa that represent single species. It was never the most productive taxon.

Hereafter, the term community type will be used for the groups of stands defined by the ordination. A community type is a purely abstract phytosociological classification unit and must be distinguished from an actual stand of vegetation (Whittaker 1978). A stand is a real entity, in the sense that it actually exists. A community type, or any other type of classification unit (e.g., species), is a conceptual entity, with its descriptive characteristics derived from the measurable characteristics of the stands from which it was developed.

Because the eight community types distinguished on Carter Mountain have been defined on the basis of shared multiple characteristics considered concurrently, they are considered to be polythetically developed (Sokal and Sneath 1963). Consequently, a sample stand that "belongs" to a given community type need not possess all of the characteristics used to define it, and no single characteristic is either essential or sufficient for inclusion in a community type.

Narrative descriptions of the important modal vegetation features and associated major soil and site attributes of the community types are given below. Summaries of data on which the descriptions are based are presented in appendix 2 (vegetation) and appendix 3 (site-soil). In the narrative, values for standing crop have been rounded to the nearest whole gram. To describe soils, the following conventions were used: Surface soil refers to the epipedons (mollic umbric, ochric) and subsoil to the subsurface horizon (cambic) or to the IIC horizon.

Geum rossii-Trifolium parryi community type (5 stands)

Structure.—A dense, generally continuous plant cover composed mainly of forbs was present in the stands representing this community type. The tallest taxon, *Geum rossii,* usually did not exceed 30 cm in height and had a clumped distribution. The clumps were roughly oblong, with the long axis parallel to the slope contour. Most associated taxa had an erect growth form. Cushion plants (plants with a compact, prostrate, caespitose growth form) were a minor component of the vegetation; grasses and graminoids were relatively abundant.

Composition.—Average aboveground standing crop was 103 g/m². *Geum rossii,* 21% of standing crop, and *Trifolium parryi,* 15%, were characteristic species. This was the only community type where *Trifolium parryi* was abundant; *Salix reticulata* was essentially restricted to this community. Important subordinate taxa were *Artemisia scopulorum, Polygonum bistortoides, Phlox multiflora, Poa* spp., *Deschampsia caespitosa,* and *Carex ebenea.* The last two taxa had low constancy. This community type may be the Absaroka analog of the "Parry's clover meadow standtype" described by Marr (1961) on Niwot Ridge in the Colorado Front Range.

Site.—The stands of this community type were present on steep lower slopes that were generally protected from strong winds. These were areas of snow accumulation, and small solifluction terraces were a characteristic feature of the landscape. These were the most mesic sites occupied by *Geum rossii.*

Soils.—Two of the five pedons were classified as Cryochrepts and two as Crumbrepts; the other was placed in the Cryoboroll subgroup. All pedons had deep sola, which were quite variable in stone content. Soil texture was sandy loam throughout. The soils were medium acid in the surface and only slightly less acidic in the subsoil. Available water ranged from 4.3% to 13.8% in the surface horizons and from 6.7% to 10.5% in the subsoil horizons.

Geum rossii-Trifolium nanum community type (7 stands)

Structure.—A somewhat open plant cover characterized by well-distributed, caespitose, clumps of *Geum rossii* that generally did not exceed 25 cm in height, was present in the stands. The ground layer was a mixture of erect forbs and cushion plant species, with the latter the more abundant group.

Composition.—*Geum rossii* contributed 35% of the average total standing crop of 101 g/m². The most abundant species in the ground layer was the prostrate legume *Trifolium nanum,* which produced 23% of standing crop. Other well-distributed, but less productive, taxa were *Poa* spp., *Phlox multiflora, Sedum lanceolatum, Cerastium arvense, Lomatium montanum, Besseya cinera,* and *Polygonum bistortoides.* Forbs produced 90% of the total standing crop. The closest analog of this community type would be the *Geum* turf of Johnson and Billings (1962) on the Beartooth Plateau.

Site.—Stands were located on moderately steep terrain. All were on windward exposures on the upper and middle portions of the slope. There was no evidence of snow accumulation, and only intermittent snow cover may occur during the winter. Rubble, gravel pavement, and bare soil were exposed on approximately half of the ground surface.

Soils.—The seven pedons were classified as Cryumbrepts (3), Cryochrept (1), Cryoborolls (2), and Cryorthents (1). Sola were stoney and, in general, shallow with sandy loam texture. Surface horizons were acidic. The subsurface horizons had reaction values as low as pH 4.9, the most acidic values recorded. Percentage available water ranged from an average of 6.7% in the surface to 6.9% in the subsoil.

Trifolium dasyphyllum-Geum rossii community type (4 stands)

Structure.—An open mosaic of cushion plants interspersed with somewhat depauperate and caespitose *Geum rossii* characterized this community type. Plants rarely exceeded 20 cm in height in any of the stands.

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Composition.—*Trifolium dasyphyllum* produced 20% of the standing crop of 134 g/m² in this community type, while *Geum rossii* produced 15%. Important subordinate taxa were *Phlox multiflora, Sedum lanceolatum, Poa* spp., *Carex obtusata, Oxytropis parryi, Lomatium montanum,* and *Arenaria congesta.* All of these taxa had 100% constancy, but low average standing crop. Cushion plants constituted 51% of the total standing crop. *Trifolium nanum* occurred only at low constancy and had a low standing crop in the *Trifolium dasyphyllum-Geum rossii* community type.

Site.—Included stands were present on the middle and upper portions of windward slopes of moderate steepness. The ground surface was at least 50% rubble, gravel pavement, and bare soil. These were the least mesic sites for *Geum rossii.*

Soils.—The pedons were classified as Cryumbrepts (2) and Cryoborolls (2) and were well developed, with cambic horizons present in three of the four profiles. Sola were shallow to moderately deep and sandy in the surface horizons. The surface horizons were the shallowest of those described. Available water in the surface soil averaged 6.6% and in the subsoil 7.9%. Soil reaction was slightly acidic throughout the sola with some values in the neutral range.

Lupinus greenii-Poa spp. community type (3 stands)

Structure.—A dense, two-layered plant cover, characterized by a single taxon of erect growth form (*Lupinus greenii*), which may reach 40 cm height, was present in the stands of this community type. The lower layer was predominantly erect forbs; cushion plants were only moderately abundant.

Composition.—The major identifying characteristic was the abundance of *Lupinus greenii.* This species provided 24% of the average standing crop of 113 g/m². The erect stems of *Lupinus greenii* trap blowing snow even during minor summertime snowstorms. Snow may reach considerable depths and remain after it has disappeared from surrounding areas. Stands of the *Lupinus greenii-Poa* spp. community type were the first to be covered by snow in the fall and may have some snow cover until relatively late in the growing season. Thus, the growth form of the dominant species may enhance the moisture regime of the site. Subordinate forbs were *Phlox multiflora, Geum rossii, Artemisia scopulorum, Solidago ciliosa, Antennaria rosea,* and *Arenaria congesta.* This and the *Geum rossii-Trifolium parryi* community type are the only ones where *Trifolium parryi* was present. Here it contributed less than 4% of the total standing crop. Forbs as a group contributed 80% of the total standing crop. Grasses contributed 18% of the average standing crop, with *Poa* spp. the major taxa. Graminoids constitued only 2% of the standing crop.

Site.—The stands of this community type were present on the middle portion of steep lee slopes where snow may persist until midsummer.

Soils.—All pedons were classified as Cryumbrepts. The average thickness of the sola was 110 cm, which was the greatest depth recorded. Surface stoniness was in the range 5-25%, the least stoney of the soils examined. The pH values were strongly acid in the surface horizons, but only moderately acid in the subsoil. Available moisture was 7.3% in the surface horizons and 10.4% in the subsoil.

Phlox pulvinata-Trifolium dasyphyllum community type (4 stands)

Structure.—A moderately dense, single-tier, plant cover of prostrate, caespitose forbs and depauperate graminoids, usually not over 20 cm in height, was present in the stands placed in this community type.

Composition.—The average aboveground standing crop was 142 g/m²—the highest of all the community types studied. *Phlox pulvinata,* which was present at low constancy and standing crop in many of the other communities, was the most characteristic taxon. Although it is a cushion plant, it produced over 100 g/m² of standing crop on one of the sites and produced an average of 26% of the standing crop for the community type. The other characteristic taxon, *Trifolium dasyphyllum,* averaged 22 g/m² and had more consistent production in all stands than *Phlox pulvinata.* *Artemisia scopulorum, Lomatium montanum, Oxytropis parryi, Phlox multiflora,* and *Arenaria congesta* were other common forb species. *Geum rossii* produced less than 1% of the total standing crop and was sparsely distributed. Grasses and graminoids were more productive in this plant community than in any of the others. Together they produced 28% of the standing crop. *Poa* spp., *Koeleria cristata, Carex elynoides,* and *C. obtusata* were the major taxa.

Site.—All stands occurred on the lee side of ridgetops on moderately steep slopes. There was a considerable amount of exposed surface rock, but grave pavement and bare soil surfaces were not as common as in some of the other previously described community types.

Soils.—Three of the four pedons were classified as Cryoborolls; one as a Cryumbrept. All had cambic horizons. Soils were moderately deep, very stoney throughout the sola and had sandy loam to loamy texture. Average soil reaction values were in the range pH 6.0-6.6. Mean available water in the surface was 4.0%. This was lowest of all described soils.

Antennaria rosea-Artemisia scopulorum community type (3 stands)

Structure.—A single-tier plant cover composed of scattered mixture of forbs, graminoids, and cushion plants usually not over 20 cm high was present.

Composition.—Taxa that occurred only as subordinates in other community types were characteristic. With the exception of *Phlox pulvinata,* taxa characteristic of other community types were eithe absent or poorly represented. Erect forbs were mor productive than the cushion plant forbs. *Antennari rosea* and *Artemisia scopulorum* produced 25% of th average standing crop of 139 g/m². *Phlox pulvinata* contributed 10% of the total standing crop. Other commo forbs were *Achillea lanulosa, Oxytropis parry*

Cerastium arvense, and *Lomatium montanum. Trifolium dasyphyllum, Arenaria congesta,* and *Sedum lanceolatum* were cushion plants with high constancy, but low standing crop. About 24% of the average standing crop was composed of grasses and graminoids. *Poa* spp., *Koeleria cristata, Festuca rubra,* and *Carex elynoides* are the most abundant taxa.

Site.—The stands in this community type were present on the lower portion of protected, relatively steep slopes. Snow accumulation on these sites was estimated to be moderate.

Soils.—Two of the soils were classified as Cryumbrepts and the other as a Cryoboroll. Sola were deep and slightly acid in both the surface and subsurface soil. Surface stoniness was variable. The clay content of the surface horizons of these soils averaged 21%. This was greater than that of the soils from the other community types. The subsoil clay content was similar to that of the other pedons. The percentage moisture held at the wilting point was the highest of all the soil groups. However, percentage available water was only moderate.

Phlox multiflora-Trifolium nanum community type (1 stand)

Structure.—The vegetation was a single layer of sparsely distributed cushion plants and depauperate forbs and graminoids.

Composition.—*Phlox multiflora, Trifolium nanum, Eritrichium nanum* var. *elongatum,* and *Festuca ovina* were the major species. Together these four species provided 80% of the average total standing crop of 63 g/m². Only eight other taxa were present.

Site.—The single stand representative of this community type was present on the upper portion of the windward side of an exposed slope of moderate steepness. This was an area of very low snow accumulation.

Soil.—The pedon was shallow (15 cm), with 80% stones. Soil reaction was slightly acid in the only horizon present. The epipedon was dark enough and contained sufficient organic carbon to be considered mollic. It was not sufficiently thick to fit this classification fully and the term "minimal-Cryoboroll" is probably appropriate.

Erigeron compositus-Poa spp. community type (2 stands)

Structure.—A very sparsely distributed vegetation of depauperate forbs and grasses was present. Maximum height of plants rarely exceeded 10 cm.

Composition.—The most abundant species was *Erigeron compositus,* which produced 35% of the aboveground standing crop of 25.9 g/m². The only other taxa with 100% constancy were *Lomatium montanum,* and the grasses *Poa* spp. and *Agropyron scribneri.* These two grass taxa, plus *Koeleria cristata,* produced 30% of the average standing crop. The very sparse, scattered distribution of the plants, the low number of taxa present, and the low productivity made it difficult to distinguish a true characteristic taxon.

Site.—This community type was found on very stoney areas on the middle portion of lee slopes.

Soils.—The two pedons were classified as a Cryorthent and a Cryogboroll. Both were poorly developed, without cambic horizons. Pedons were shallow, rocky, and sandy, with slightly acidic reaction. Percentage available water was relatively high in the surface horizon.

Classification

There is a large degree of floristic similarity between the alpine community types on Carter Mountain. Differences are due mainly to shifts in the standing crop and constancy of a few species rather than distinctly different floristic composition. Very few species are confined to a given community type and, as had been found elsewhere, while many species may be present, the bulk of the standing crop is contributed by relatively few species (Scott and Billings 1964).

Because of their floristic similarity, it is possible the community types represent successional seres. However, the applicability of the classic concepts of climax and succession to the alpine zone has been questioned (Churchill and Hansen 1958, Billings and Mooney 1959). On Carter Mountain the vegetation has had a long history of domestic sheep grazing, which has influenced the present floristic composition. It would be considered "disturbed" and successional relationships would be obscured. It appears best to consider the community types on the basis of what they are at the time the stands are sampled, not what they might, or should, become.

Perennial forbs are the dominant life-form in all of the community types. With the possible exception of *Lupinus greenii,* all of the indicator taxa commonly occur throughout the alpine zone in the central and northern Rocky Mountains. The vegetation reflects the generally dry nature of the entire study area, caused by the porous nature of the geological substratum and the steep slope gradients. The situation on Carter Mountain is representative of much of the volcanic portion of the Absaroka Range. Flat or concave sites where hydrophytic vegetation might develop are very limited and the wet meadow or low shrub vegetation of other Rocky Mountain alpine areas is absent.

Although most of the community types had generally comparable taxa composition, similarity analysis indicated they were rather dissimilar. When similarity coefficients were calculated using only the 20 taxa also used for ordination, the maximum similarity coefficient between two community types was 52.4%. Only 3 (of 28) similarity coefficients were greater than 50% and most (21 of 28) were less than 40% (table 2). The minimum similarity coefficient was 9.9%.

Similarity coefficients calculated with all 60 taxa were only slightly different (table 3). The overall effect of adding 40 taxa was a very slight reduction in the levels of most of the similarity coefficients. However, the levels of both the maximum and minimum similarity coefficients were slightly increased. The increase in the maximum coefficients was accompanied by a change in the relationships between the three

Table 2.—Matrix of similarity between eight alpine community-types based on 20 taxa.

	Gero-Trpa	Gero-Trna	Trda-Gero	Lugr-Poa	Phpu-Trda	Anro-Arsc	Phmu-Trna	Erco-Poa
Gero-Trpa	*	52.4	45.0	43.1	23.7	37.7	19.2	16.3
Gero-Trna		*	50.2	29.3	14.2	29.3	37.9	18.5
Trda-Gero			*	38.2	44.6	44.5	33.5	16.6
Lugr-Poa				*	38.2	39.2	22.1	14.7
Phpu-Trda					*	44.5	33.5	16.6
Anro-Arsc						*	9.9	11.2
Phum-Trna							*	24.5
Erco-Poa								*

Table 3.—Matrix of similarity between eight alpine community-types based on 60 taxa.

	Gero-Trpa	Gero-Trna	Trda-Gero	Lugr-Poa	Phpu-Trda	Anro-Arsc	Phmu-Trna	Erco-Poa
Gero-Trpa	*	47.1	39.7	41.0	22.6	32.3	16.5	11.8
Gero-Trna		*	53.9	29.3	15.9	30.6	35.5	20.1
Trda-Gero			*	36.0	44.0	41.4	30.5	19.7
Lugr-Poa				*	27.0	44.4	19.7	13.6
Phpu-Trda					*	47.8	30.6	11.5
Anro-Arsc						*	16.0	19.4
Phmu-Trna							*	17.1
Erco-Poa								*

community types where *Geum rossii* was a characteristic taxon. No such change occurred at the minimum level.

Cluster analysis further clarified the relationships between community types and allowed them to be classified at several levels (fig. 2). The associations between community types were very much alike for both the 20-taxa and 60-taxa cluster analyses. The most significant change in association was the replacement of the *Geum rossii-Trifolium parryii* community type by the *Trifolium dasyphyllum-Geum rossii* community type as the closest associate of the *Geum rossii-Trifolium nanum* community type. The increased number of taxa also eliminated the very low similarity pairing of the *Phlox multiflora-Trifolium nanum* community type and the *Erigeron compositus-Poa* spp. community type. The latter was the least alike of all community types for the 20-taxa and 60-taxa cluster analyses, and the arrangement of the 60-taxa cluster analysis is preferable.

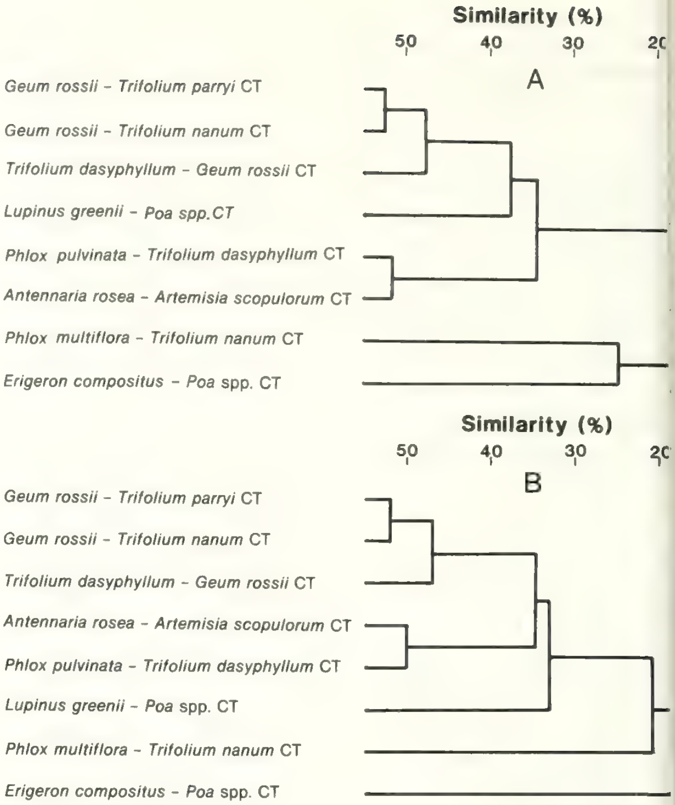
Similarity (%)
50
40
30
20
A
Geum rossii - Trifolium parryi CT
Geum rossii - Trifolium nanum CT
Trifolium dasyphyllum - Geum rossii CT
Lupinus greenii - Poa spp.CT
Phlox pulvinata - Trifolium dasyphyllum CT
Antennaria rosea - Artemisia scopulorum CT
Phlox multiflora - Trifolium nanum CT
Erigeron compositus - Poa spp. CT
Similarity (%)
50
40
30
20
B
Geum rossii - Trifolium parryi CT
Geum rossii - Trifolium nanum CT
Trifolium dasyphyllum - Geum rossii CT
Antennaria rosea - Artemisia scopulorum CT
Phlox pulvinata - Trifolium dasyphyllum CT
Lupinus greenii - Poa spp. CT
Phlox multiflora - Trifolium nanum CT
Erigeron compositus - Poa spp. CT

Figure 2.—Dendrogram of similarity between eight alpine community-types based on (A) 20 taxa, and (B) 60 taxa.

The slightly different associations between community types had no effect on the classification of the community types into higher order clusters at several levels of increasing simplicity. At the first level of agglomeration five clusters can be defined. Applying the same nomenclatural procedure used for the designation of community types, these five clusters are:

Geum rossii-Trifolium spp.
Lupinus greenii-Poa spp.
Phlox pulvinata-Artemisia scopulorum
Phlox multiflora-Trifolum nanum
Erigeron compositus-Poa spp.

The next logical agglomeration combines the *Lupinus greenii-Poa* spp. community type with the *Geum rossii-Trifolium* spp. cluster. The other clusters remain unchanged. Thus, agglomeration provides four clusters with the standing crop of *Geum rossii* as the key descriptive attribute. *Geum rossii* is abundant in the first cluster at this level with an average standing crop of 23.7 g/m². Its standing crop falls to only 1.1 g/m² in the second cluster, and it is absent from the last two clusters. A final agglomeration can be made by combining both lower order clusters containing *Geum rossii*, which allows a "*Geum*:No-*Geum*" separation to be made on the 20-taxa cluster analysis, but not on the 60-taxa cluster analysis where two community types without *Geum rossii* will be present. These latter represent only about 10% of the stands.

There is little reason to proceed beyond the first agglomeration. First, because the levels of similarity at which further agglomerations are made are below 35% and consequently the vegetation types are quite internally diverse. More importantly, the five-cluster agglomeration provides a set of utilitarian subdivisions of the vegetation. Stands representative of the five vegetation units are readily identified in the field and may be detected and delineated on aerial photographs. Thus, the vegetation units at this level can serve as the basis for vegetation mapping units and as rangeland inventory units at the management level. For other management or research purposes, such as studies of forage nutrition, productivity or utilization, the information that finer variations (community types) are present will be useful.

The eight community types also may be grouped into four physiognomic types:

- Turf plant-type
  - *Geum rossii-Trifolium parryi* community type
  - *Geum rossii-Trifolium nanum* community type
  - *Trifolium dasyphyllum-Geum rossii* community type
- Herb meadow-type
  - *Lupinus greenii-Poa* spp. community type
- Cushion plant-type
  - *Phlox pulvinata-Trifolium dasyphyllum* community type
  - *Antennarria rosea-Artemisia scopulorum* community type
  - *Phlox multiflora-Trifolium nanum* community type
- Scree plant-type
  - *Erigeron compositus-Poa* spp. community type

The *Erigeron compositus-Poa* spp. community type has been called a scree plant-type because the ground surface is characterized by loose, cobblestone-shaped rocks rather than the more angular and somewhat imbedded rocks usually associated with fellfields.

VEGETATION-SOIL RELATIONSHIPS

There were no close relationships between the classification of vegetation into community types (or higher order classification units) and the classification of soils. Soil with dark-colored surface horizons (umbric or mollic epipedons) and relatively well-developed subsurface horizons (usually a cambic horizon) occurred on 26 of the 29 stands sampled. The dark-colored, organic-rich epipedons are a direct contribution of the vegetation to soil morphology and they are present on almost all of the sites where the vegetation was sufficient to allow a significant amount of litter and roots to accumulate and decompose.

The distinction between the two types of epipedons is based on many factors, the most important being the thickness of the epipedon, organic content, and the prevalence of bivalent cations. An umbric epipedon does not have high bivalent cation saturation and may be simply described as an acidic mollic epipedon. The kind of epipedon present is very important in the classification of the soils on Carter Mountain, but the presence of a certain kind of epipedon did not seem to be related to the vegetation classification. There is no sound biological reason why two abstraction systems (classifications), each based on a set of different attributes, should coincide. This does not imply vegetation and soil are unrelated. It does mean the relationship is a functional one and cannot be expressed by comparisons between classifications.

This may be particularly true when the classification processes are opposites. The soils were classified by logical division for the purpose of identifying a soil individual (Great Group, Soil Series, etc.) The vegetation on Carter Mountain was classified by an agglomerative process which had as its endpoint the development of the vegetation groups which have been called community types.

ENVIRONMENTAL RELATIONSHIPS

Plant-environment relationships are considered more important in the alpine than inter- or intraspecies relationships, and the vegetation is regarded as a complex mosaic of community types arranged along environmental gradients (Billings and Mooney 1968). Topographic site, degree, and duration of snow cover and exposure to wind are the major environmental influences. Their combined effect is basically a gradient of available moisture and temperature.

The sample stands of alpine vegetation on Carter Mountain were grouped by their relationships to the first three principal components. These were based on taxa composition and biomass. According to van Groenewoud (1965) each of the principal components also may indirectly represent a compound variable of several environmental factors. The significantly correlated site and soil factors are given in table 4.

The first principal component may be interpreted as a combination of elevation and exposure to wind plus soil factors associated with particle size distribution in the solum. Elevation was the most significant variable on the first principal component. It is in itself a compound variable, but is often expressed in terms of its effect on temperature. The 440-m change in elevation between the highest and lowest sites could be interpreted as an average difference of 2.4° C in mean air temperature over the range in site elevations. In areas where the average growing season temperature is close to the freezing point, this difference might be critical for some species. The effects of wind in the alpine are well known (Billings and Mooney 1968), and exposure to wind was the second most highly correlated site factor on the first principal component.

The clay content of the solum was the most significant soil attribute on the first principal component. Clay content decreased with increasing elevation, while sand content increased. The greater proportion of sand might be caused by increased potential for wind erosion of the soil fines at higher elevations or by illuviation. Several of the other significant soil factors are those often associated with the clay fraction, e.g., cation exchange capacity, percent of water at 15 bars tension (wilting point), and the K^+ and Mg^+ levels.

Table 4.—Correlation and statistical significance of site and soil attributes on the first three principal components.

	Principal components[1]		
	V1	V2	V3
Significant[2] site attributes			
Elevation	0.66**	0.43*	
Exposure to wind	-0.51*	-0.51*	-0.55*
Position on slope		0.44*	-0.62**
Slope angle			-0.62
Snow accumulation			-0.80**
Significant[3] soil attributes			
Sand content	0.44*		
Clay content	-0.61**		
Silt content		-0.40*	
Coarse fragment (+2 mm) content			0.45*
Water content (15 bars)	-0.48*		
Available water		0.45*	
Soil reaction		-0.49*	0.38*
Cation exchange capacity	-0.57*		
Potassium content	-0.51*		
Magnesium content	-0.38*		

[1] *** Significant at $\alpha = 0.01$; * significant at $\alpha = 0.05$.*

[2] *Nonsignificant site attributes: slope aspect.*

[3] *Nonsignificant soil attributes: solum depth; organic matter content; water content (1/3 bar); Kjeldahl nitrogen; phosphorus content; calcium content; sodium content; base saturation; ferricoxide content.*

The exposure to wind and elevation were again significant site attributes on the second principal component, as was the position of the stand on the slope relative to the ridgeline. Exposure to wind was indirectly related to elevation, while position on slope was directly related.

Three soil factors were significant on the second principal component: the silt fraction and the percentage of water available between 1/3 and 15 bars tension, and soil reaction (pH). The percentage of available water was the most significant of all factors on the second principal component. This can be interpreted as an index of the ability of the soil to hold water and to supply it to the plants. This ability is related to the textural composition of the soil where, of the three textural classes, the silt fraction may represent a "happy medium" where there is sufficient porosity to hold water, but water is not held so tightly it is unavailable (which may occur in the clay fraction) or so loosely it is lost through percolation (as in the sand fraction). The importance of soil reaction (pH) to alpine plants is unknown. Extremely acidic or basic pH can influence the availability of mineral ions in the soil, but the pH ranges in the Carter Mountain soils were not extreme enough to materially influence ion uptake.

The most important factor on the third principal component is snow accumulation. Three habitat factors associated with snow accumulation—position on slope, slope angle, and exposure to wind—are also significant. The only soil factors to be significantly related are the coarse fragment (+2 mm) content of the solum and soil pH.

A statistically significant correlation between a site or soil factor and the eigenvalues of the principal components does not imply a cause and effect relationship, but merely indicates the possibility of relationships between many different environmental factors and the distribution of alpine species and, consequently, alpine plant communities.

That several factors were significant in a given principal component may be interpreted to mean plant distribution is controlled by a combination of several factors and not by a single factor. The significance of such factors as elevation, exposure to wind, snow accumulation, and the availability of soil water have been recognized by alpine ecologists as controlling influences in the distribution of alpine plants. The influence of factors such as snow accumulation on plant species may be empirically deduced. However, the influence of factors such as soil texture, cation exchange capacity, soil reaction, or the level of particular soil cations cannot be fully explained without considerable knowledge of the autecological requirements of the individual species, and this knowledge is not yet available for any of the species.

LITERATURE CITED

Beetle, Alan A. 1970. Recommended plant names. Agricultural Experiment Station Research Journal 31. 124 p. University of Wyoming, Laramie.

Billings, W. D., and H. A. Mooney. 1959. An apparent frost hummock-sorted polygon cycle in the alpine tundra of Wyoming. Ecology 40:16-20.

Billings, W. D., and H. A. Mooney. 1968. The ecology of arctic and alpine plants. Biological Review 43:481-529.

Churchill, E. D., and H. C. Hanson. 1958. The concept of climax in arctic and alpine vegetation. Botanical Review 24:127-191.

Johnson, Phillip L., and W. D. Billings. 1962. The alpine vegetation of the Beartooth Plateau in relation to cryopedogenic processes and patterns. Ecological Monographs 32:105-135.

Love, J. D., J. L. Weitz, and R. K. Hose. 1955. Geologic map of Wyoming, 1:500,000. U.S. Geological Survey, Washington, D.C.

Marr, J. W. 1961. Ecosystems of the east slope of the Front Range in Colorado. University of Colorado Studies Series in Biology No. 8. 134 p. Boulder.

Nimlos, T. J., and R. C. McConnell. 1962. The morphology of alpine soils in Montana. Northwest Science 36:99-112.

Scott, D., and W. D. Billings. 1964. Effects of environmental factors on standing crop and productivity of an alpine tundra. Ecological Monographs 34:243-270.

Scott, Richard W. 1966. The alpine flora of northwestern Wyoming. M.S. thesis, 219 p. University of Wyoming, Laramie.

Sokal, R. R., and P. H. A. Sneath. 1963. Principals of numerical taxonomy. 359 p. W. H. Freeman and Co., San Francisco, Calif.

Sorenson, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to the analysis of the vegetation on Danish commons. Biologiske Skrifter 5:1-34.

Strasia, C. A., M. Thorn, R. W. Rice, and D. R. Smith. 1970. Grazing habits, diet and performance of sheep on an alpine range. Journal of Range Management 23:201-208.

U.S. Department of Agriculture, Soil Conservation Service. 1975. Soil taxonomy. Agriculture Handbook 436, 754 p. Washington, D.C.

van Groenewoud, H. 1965. Ordination and classification of Swiss and Canadian coniferous forest by various biometric and other methods. Berichte des Geobotanischen Institutes der Eidg. Techn. Hochschule Stiftung Rubel 36:28-102.

Whittaker, Robert H. 1978. Approaches to classifying vegetation. p. 1-19. *In* Classification of Plant Communities. Robert H. Whittaker, editor. Dr. W. Junk bv Publishers The Hague, Boston 1978. 408 p.

Wyoming Water Planning Program, in cooperation with ESSA Weather Bureau State Climatologist, Wyoming. n.d. Mean annual precipitation as of 1965 (in inches). Overprint on Physiographic Map of Wyoming, 1:500,000 scale. U.S. Geological Survey, Washington, D.C.

APPENDIX 1. Morphology of typical soil subgroups from the alpine zone, Carter Mountain, Wyoming.

Soil subgroup	Horizon	Depth (cm)	Color (Munsell)	Texture; Coarse fragments	Structure consistency	Reaction (pH)	Bounda
Pergelic Cryorthent, fragmental, mixed (2 of 29 pedons)	A1	0–10	10YR5/2 dry 10YR3/2 moist	Sandy loam; 40% gravel gravel, cobble, stones	Strong, fine crumb and granular; soft, friable, nonsticky, nonplastic	6.1	Broken, irregular
	IIC	10+		Fragmented volcanic breccia, tuff, ash			
Pergelic Cryochrept, coarse-loamy over fragmental, mixed (2 of 29 pedons)	A1	0–10	2.5YR6/2 dry 2.5YR4/2 moist	Sandy loam; 20–35% angular and rounded stones	Weak, fine crumb; soft, soft, very friable nonsticky, nonplastic	6.3	Clear, wavy
	B2	10–74	2.5YR6/3 dry 2.5YR4/3 moist	Gravelly, sandy loam	Weak, fine crumb; soft, very friable, nonsticky, nonplastic	6.3	Abrupt, wavy
	11C	74+		Fragmented volcanic breccia			
Andic Pergelic Cryochrept, loamy-skeletal over fragmental, mixed (1 of 29 pedons)	A1	0–8	10YR6/2 dry 10YR4/2 moist	Channery, sandy loam; 15–20% angular fragments of volcanic breccia, tuff	Weak, fine crumb; soft, very friable, nonsticky, nonplastic	5.6	Abrupt, wavy
	B21	8–18	10YR6/4 dry 10YR4/3 moist	Very channery loam; 50–60% angular fragments 3–15 cm long	Weak, fine crumb; soft, very friable, nonsticky, nonplastic	5.7	Abrupt, Wavy
	B22	18–33	10YR7/3 dry 10YR5/3 moist	Very channery loam; 50–60% angular fragments 3–15 cm long	Weak, fine crumb; soft, very friable nonsticky, nonplastic	5.7	Diffuse, irregular
	B23						
	IIC	66+		Fragmented volcanic breccia			
Andic Entic Pergelic Cryumbrept, loamy-skeletal over fragmental, mixed (6 of 29 pedons)	A11	0–8	10YR5/2 dry 10YR3/2 moist	Sandy loam; 50% stones	Strong, fine crumb; soft very friable, nonsticky, nonplastic	6.6	Gradual, smooth
	A12	8–33	10YR5/3 dry 10YR3/2 moist	Sandy loam; 50% stones	Strong, fine crumb; soft, very friable nonsticky, nonplastic	6.4	Broken, wavy
	IIC	33+		Fragmented, volcanic breccia, tuff, large stones with open interstices			
Andic Pergelic Cryumbrept (8 of 29 pedons)	A11	0–8	10YR5/3 dry 10YR3/3 moist	Fine, sandy loam	Weak, very fine crumb; soft very friable nonsticky, nonplastic	5.2	Clear, wavy
	A12	8–18	10YR5/3 dry 10YR3/3	Fine sandy loam; 5–15% coarse sub-rounded and angular fragments	Weak, very fine crumb; soft, very friable	5.2	Clear, wavy
	B21	18–48	10YR6/3 dry 10YR4/3 moist	Sandy loam; 15–25% coarse subrounded and angular fragments	Weak, medium, and fine subangular blocky; soft, very friable, nonsticky, nonplastic	5.8	Diffuse, irregular
	B22	48–102	10YR6/3 dry 10YR4/3 moist	Very channery, sandy loam; 65–80% channery 3–15 cm long	Structureless; soft, very friable, nonsticky, nonplastic	6.2	Diffuse, irregular
	IIC	102+		Fragmented volcanic breccia			

APPENDIX 1.—Continued

oil subgroup	Horizon	Depth (cm)	Color (Munsell)	Texture; Coarse fragments	Structure consistency	Reaction (pH)	Boundary
ndic Pergelic ryoboroll, ragmental, mixed	A1	0–15	10YR5/3 dry 10YR3/3 moist	Gravelly, sandy loam; 60–70% rounded and angular volcanic conglomerate cemented by tuff	Weak, very fine crumb; loose when dry and moist, nonsticky, nonplastic	6.2	Diffuse, irregular
	IIC	15+		Fragmented volcanic breccia			
ndic Pergelic ryoboroll, loamy-keletal, mixed of 29 pedons)	A11	0–8	10YR5/2 dry 10YR3/2 moist	Sandy loam; 60% stones	Strong, fine crumb; soft, very friable, nonsticky, nonplastic	6.6	Gradual, smooth
	A12	8–36	10YR5/3 dry 10YR4/3 moist	Sandy loam; 60% stones	Strong, fine crumb; soft, very friable	6.6	Gradual, wavy
	B2	36–71	10YR5/3 dry 10YR4/3 moist	Sandy loam; 60% stones	Weak, fine subangular blocky; slightly hard, very friable, nonsticky, nonplastic	6.4	Gradual, wavy
	C	71+	10YR5/3 dry 10YR4/3 moist	Sandy loam; 80% stones	Massive; slightly hard, very friable, nonsticky, nonplastic	6.2	

APPENDIX 2. Average standing crop (SC) in grams per square meter, dry weight, percentage composition by weight (CW), and percentage constancy (CT) for taxa in eight community types of the alpine zone, Carter Mountain, Wyoming.

Taxa¹	*Geum rossii-Trifolium parryi* (n = 5)			*Geum rossii-Trifolium nanum* (n = 7)			*Trifolium dasyphyllum-Geum rossii* (n = 4)			*Lupinus greennii-Poa* spp. (n = 3)			*Phlox pulvinata-Trifolium dasyphyllum* (n = 4)			*Antennaria rosea-Artemisia scopulorum* (n = 3)			*Phlox multiflora-Trifolium nanum* (n = 1)			*Erigeron compositus-Poa* spp. (n = 2)			All community types (n = 29)		
	SC	CW	CT	SC	CW	CT	SC	CW	CT	SC	CW	CT	SC	CW	CT	SC	CW	CT	SC	CW	CT	SC	CW	CT	SC	CW	CT
Erect forbs																											
******Geum rossii*	21.6	21	100²	35.1	35	100	20.2	15	100	5.0	4	100	0.6	X	50	1.7	1	33							16.4	15	72
**Trifolium parryi*	14.9	15	100							3.7	3	100													2.8	3	21
**Lupinus greeni*	1.1	1	40	1.1	1	28	3.3	3	50	27.6	24	100				2.5	2	67							4.4	4	38
**Lomatium montanum*				1.5	2	86	2.4	2	100	0.1	X	33	6.9	5	100	1.5	1	100	1.9	4	N⁵	1.1	6	100	1.9	2	69
**Artemisia scopulorum*	8.0	8	100	1.8	2	71	2.2	2	50	4.7	4	100	8.6	6	100	14.1	12	100							5.3	5	69
**Polygonum bistortoides*	2.7	3	100	2.9	3	71	1.2	1	50	3.5	3	100	T	X	50	2.2	2	67							1.9	2	66
**Oxytropis parryi*				0.1	X	14	2.5	2	100	2.7	2	33	5.3	4	100	4.6	4	100							1.9	2	49
**Cerastium arvense*	0.7	1	80	2.0	2	86	0.6	X	100	4.1	4	100	0.2	X	75	3.5	3	100	0.6	1	N	0.3	2	50	1.5	1	83
**Solidago ciliosa*	1.5	2	40	T	X	14	0.5	X	50	6.6	6	33	T	X	25	1.7	1	33				T	X	50	1.2	1	31
Potentilla diversifolia	1.3	2	60	1.0	1	71	0.5	X	50	1.7	2	67				1.3	2	67							2.1	2	59
Erigeron compositus	T³	X⁴	20	0.6	1	28	3.4	3	25				0.4	X	25	1.0	X	67				6.8	35	100	1.2	1	28
Polemonium viscosum	0.3	X	20	0.7	1	71	T	X	25	1.4	1	67				0.2	X	33							0.4	X	38
Myosotis alpestris	0.5	X	80	0.6	X	57	1.3	1	25	1.3	1	100	0.3	X	50	0.8	X	67							0.6	X	62
Achillea lanulosa	0.3	X	40	0.3	X	14	0.2	X	50	1.0	1	100				2.8	3	100				1.3	7	50	0.6	X	41
Besseya cinera	0.3	X	80	1.0	1	86	0.7	X	25	T	X	67	T	X	25	1.7	1	67	1.6	3	N				0.6	X	62
Agoseris glauca	0.6	1	20	0.2	X	28	0.5	X	50	1.5	1	67	T	X	25	0.4	X	33							0.4	X	35
Erigeron simplex	0.9	1	40	0.1	X	43	0.3	X	25	2.6	2	67	0.2	x	25	2.6	2	67	1.1	2	N				0.7	X	38
Potentilla plattenensis				0.7	1	43	0.5	X	25				0.4	X	25	0.2	X	33				0.7	4	50	0.4	X	35
Senecio fremontii				T	X	14				0.7	1	67	T	X	25	0.9	X	33							0.3	X	28
Mertensia alpina	0.7	1	60	0.3	X	57	0.5	X	25																0.2	X	31
Saxifraga rhombidea	0.5	X	80	0.4	X	28				T	X	33				0.2	X	33							0.2	X	24
Epilobium alpinum	0.1	X	20	0.2	X	28	0.2	X	50	T	X	33	0.1	X	25	T	X	33							0.1	X	28
Salix reticulata	4.1	4	20										0.1	X	25										0.7	X	3
Castilleja rhexifolia	T	X	20							T	X	67													T	X	11
Castilleja pulchella													T	X	25	0.2	X	33							T	X	7
Pedicularis groenlandica																T	X	33							T	X	3
Pedicularis parryi							1.2	X	25							T	X	33							0.1	X	7
Crepis nana	1.2	2	20													1.7	1	33							0.1	X	10
Collomia linearis				T	X	14																			T	X	3
Penstemon procerus																T	X	33							T	X	3
Dodecatheon conjugens	T	X	20							T	X	33				0.2	X	67							T	X	10
Delphinium nelsoni	0.1	X	20							T	X	33													T	X	7
Astragalus alpinus																0.1	X	33							T	X	3

Cushion plant forbs																											
**Trifolium dasyphyllum*				2.5	3	28	26.1	20	100				32.5	22	100	4.0	4	100				0.1	X	50	9.7	9	56
**Trifolium nanum*	3.6	4	20	23.3	23	100	4.4	3	50	0.9	X	67							11.4	23	N				6.4	6	31
**Phlox pulvinata*	0.1	X	40	0.4	X	28	3.6	3	75	0.3	X	33	38.0	26	100	11.3	10	100							7.1	7	56
**Phlox multiflora*	2.2	2	80	5.8	6	100	13.2	10	100	8.4	7	100	2.4	2	100	1.8	2	67	14.0	28	N				5.4	5	83
**Arenaria congesta*	0.9	1	40	1.4	1	43	4.3	3	100	6.6	6	67	1.6	1	100	0.5	X	100				1.1	6	50	2.1	2	59
**Sedum lanceolatum*	0.9	1	80	4.5	5	71	10.9	8	100	0.7	X	67	0.2	X	50	4.4	4	100				2.1	11	50	3.5	3	72
Antennaria rosea	0.5	X	20				2.0	2	75	4.6	4	100	2.7	3	75	14.8	13	100							2.3	2	41
Eritrichium elongatum	T	X	20	1.6	2	57	2.1	2	75				1.1	1	50	1.7	1	67	8.2	16	N				1.3	1	41
Standing crop:	8.3	8		39.5	39		66.6	51		21.5	19		78.5	56		38.5	34		32.6	66		3.3	17		38.0	35	
Grasses																											
**Poa* spp.	11.3	11	100	4.3	4	100	6.8	5	100	15.7	14	100	22.2	15	100	9.2	8	100	3.7	7	N	4.4	22	100	9.9	9	100
**Koeleria cristata*	0.3	X	20	0.2	X	57	3.3	3	50	2.0	2	33	6.0	4	100	5.2	5	100				0.9	5	50	2.2	2	59
**Festuca rubra*	0.8	1	40	0.1	X	28	4.1	3	75				1.5	1	75	5.3	5	100							1.5	1	41
Agropyron scribneri				1.3	1	57	2.3	2	75	0.4	X	33	0.4	X	50	0.8	X	33	0.9	2	N	0.9	5	100	1.2	1	45
Deschampsia caespitosa	4.1	4	40	0.8	1	57				1.2	1	67													0.8	1	14
Festuca ovina	0.8	1	40							0.6	X	67							7.7	15	N				0.5	X	38
Agropyron trachycaulum				0.3	X	57	0.6	X	25				0.2	X	50										0.4	X	14
Trisetum spicatum	T	X	20				T	X	25	1.0	1	67													0.2	X	24
Hesperochloa kingii	T	X	20																						0.1	X	7
Standing crop:	17.4	17		7.0	7		17.1	13		20.9	18		30.2	21		20.5	18		12.3	24		6.2	32		16.8	16	
Graminoids																											
*Carex albonigra	3.2	3	60	2.6	3	57	0.1	X	25							0.5	X	33							1.2	1	31
**Carex elynoides*				0.1	X	14	1.0	1	50	T	X	33	7.9	6	100	5.4	5	33							0.9	1	28
Carex ebenea	10.3	10	60							1.4	1	33													2.0	2	17
Carex obtusata	1.7	X	40	0.4	X	43	6.3	5	75	T	X	33	1.9	1	100	0.5	X	33	0.2	X	N				1.9	2	45
Luzula spicata	0.2	2	80	0.3	X	57	0.2		75	0.5	X	67				0.2	X	33							0.2	X	48
Standing crop:	15.4	15		3.4	3		7.6	6		2.0	2		9.8	7		6.6	6		0.2	X		.0			6.2	6	
Standing crop: All forb taxa	70.0	68		90.4	90		108.9	82		90.0	80		101.6	72		85.0	76		37.8	76		13.5	68		84.6	78	
Standing crop: Grass and graminoid taxa	32.8	32		10.4	10		24.7	18		22.9	20		40.1	28		27.1	24		12.5	24		6.2	32		23.0	22	
TOTAL STANDING CROP	102.8			100.8			133.6			112.9			141.7			112.1			50.3			19.7			107.6		

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[1] *Asterisk indicates taxa utilized in principal component analyses.*

[2] *Underlining indicates characteristic taxa for each plant community type.*

[3] *T: Less than 0.1 g/m²; a value of 0.05 g/m² was used in calculation of totals.*

[4] *X: Less than 1% composition.*

[5] *N: Not calculated, only 1 sample.*

APPENDIX 3. Major[1] habitat features and average soil properties of eight alpine community types, Carter Mountain, Wyoming.

Significant attributes	Horizon[2]	PLANT COMMUNITIES *Geum rossii-Trifolium parryi* (n = 5)	*Geum rossii-Trifolium nanum* (n = 7)	*Trifolium dasyphyllum Geum rossii* (n = 4)	*Lupinus greenii-Poa spp* (n = 3)	*Phlox pulvinata-Trifolium dasyphyllum* (n = 4)	*Antennaria rosea-Artemisia scopulorum* (n = 3)	*Phlox multiflora Trifolium nanum* (n = 1)	*Erigeron Erigeron compositus Poa spp.* (n = 2)
Habitat features									
Elevation (meters)		3235	3345	3345	3235	3220	3170	3225	3255
Slope aspect		All	North, west, east	South, east	East, west	South, east north	South, east	West	South, east
Slope angle (%)		40	32	28	50	32	44	38	47
Position on slope		Lower ⅓	Mid and upper⅔	Mid and upper ⅔	Mid ⅓	Ridgetop	Lower ⅓	Upper ⅓	Mid ⅓
Exposure to prevailing wind		Lee	Windward	Windward	Lee	Lee	Lee	Windward	Lee
Snow accumulation		Deep	Shallow	Shallow	Deep	Shallow	Moderate	Shallow	Moderate
Snow duration		Long	Short	Short	Long	Short	Moderate	Short	Moderate
Soil properties									
Coarse fragments 2 mm (%)	Surface Subsoil	22 52	43 68	37 35	13 50	61 70	34 47	80	60
Sands 2 mm; 0.02 mm (%)	Surface Subsoil	60 56	54 63	62 59	56 55	59 60	52 51	52	67
Silts 0.02mm; 0.002mm (%)	Surface Subsoil	29 31	27 28	25 23	29 24	26 28	27 26	36	21
Clays 0.002 mm (%)	Surface Subsoil	12 13	10 10	14 13	14 22	14 12	21 23	12	13
Water available ⅓ to 15 bar (%)	Surface Subsoil	9.0 9.0	6.7 6.9	6.6 7.9	7.3 10.4	4.0 7.4	6.3 9.7	8.5	6.8
Water retained at 15 bar (%)	Surface Subsoil	13.5 11.6	11.4 9.6	12.0 12.8	13.4 11.0	13.3 14.2	14.9 16.3	16.4	9.3
Cation exchange capacity (meq/100 g)	Surface Subsoil	22.2 20.0	18.1 17.5	19.6 24.8	19.0 20.0	21.2 27.8	25.3 28.0	14.1	20.8
Soil reaction (pH)	Surface Subsoil	5.6[3] 6.1	5.9 5.7	5.9 6.3	5.1 6.1	6.4 6.4	6.3 6.1	6.4	6.2
Potassium content (meq/100 g)	Surface Subsoil	0.45 0.34	0.37 0.16	0.45 0.20	0.69 0.41	0.63 0.45	0.64 0.58	0.75	0.24
Magnesium (meq/100 g)	Surface Subsoil	5.3 4.8	4.3 2.8	5.1 5.6	3.4 4.9	5.4 6.0	4.4 5.6	8.0	5.1

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[1] Statistically significant at = 0.05 on the first three eigenvectors derived from principal component analysis.

[2] Diagnostic epipedon (i.e., A1 horizon). Cambic horizon (i.e., B2 horizon).

APPENDIX 4. Alphabetical list of scientific and common names of plants.[1]

Trees and Shrub (non-alpine taxa)

Abies lasiocarpa (Hook.) Nutt.	subalpine fir
Picea engelmannii Parry ex Engelm.	Engelmann spruce
Pinus flexilis James	limber pine
Artemisia tridentata Nutt.	big sagebrush

Erect Forbs

Achillea lanulosa Nutt.	western yarrow
Agoseris glauca (Pursh) Raf.	pale agoseris
Arnica fulgens Pursh	orange arnica
Artemisia scopulorum A. Gray	alpine sagewort
Astragalus alpinus L.	alpine milkvetch
Besseya cinera (Raf.) Penn.	Wyoming kittentails
Castilleja pulchella Rydb.	indianpaintbrush
Castilleja rhexifolia Rydb.	splitleaf indianpaintbrush
Cerastium arvense L.	starry cerastium
Cirsium polyphyllum (Rydb.) Petr.	thistle
Collomia linearis Nutt.	narrowleaf collomia
Crepis nana Richards.	tiny hawksbeard
Delphinium nelsonii Greene	Nelson larkspur
Dodecatheon conjugens Greene	sailorscap shootingstar
Draba aurea M. Vahl.	golden draba
Epilobium, alpinum L.	alpine willowherb
Erigeron compositus Pursh	fernleaf fleabane
Erigeron simplex Greene	oneflower fleabane
Geum rossii (R. Br.) Ser.	alpine avens
Lewisia pygmaea (A. Gray) Robins.	dwarf Lewisia
Lomatium montanum C. & R.	mountain lomatium
Lupinus greenii A. Nels.	Green lupine
Mertensia alpina (Torr.) G. Don	alpine bluebells
Myosotis alpestris Schmidt.	alpine forgetmenot
Oxytropis parryi A. Gray	Parry loco
Pedicularia groenlandica Retz.	elephanthead lousewort
Pedicularis parryi A. Gray	Parry lousewort
Penstemon procerus Dougl. ex Graham	littleflower penstemon
Polemonium viscosum Nutt.	sticky polemonium
Polygonum bistortoides Pursh	americanbistort knotweed
Potentilla diversifolia Lehm.	blueleaf cinquefoil
Potentilla plattenensis Nutt. ex T. & G.	Platte cinquefoil
Ranunculus sp. L.	buttercup
Salix reticulata L.	netleaf willow
Saxaifraga rhombidea Greene	diamondleaf saxifrage
Senecio fremontii T. & G.	Fremont groundsel
Solidago ciliosa Greene	hairy goldenrod
Trifolium parryi A. Gray	Parry clover

APPENDIX 4. Alphabetical list of scientific and common names of plants.[1]

Cushion Plant Forbs	
Antennaria rosea Greene	rose pussytoes
Arenaria congesta Nutt. ex T. & G.	ballhead sandwort
Eritrichium elongatum (Rydb.) Wright	falseap lineforgetmenot
Phlox multiflora A. Nels.	flowery phlox
Phlox pulvinata (Wherry) Cronquist	cushion phlox
Trifolium dasyphyllum T. &. G.	whiproot clover
Trifolium nanum Torr.	dwarf clover
Sedum lanceolatum Torr.	yellow stonecrop
Grasses	
Agropyron scribneri Vasey	Scribner wheatgrass
Agropyron trachycaulum (Link) Malte	slender wheatgrass
Deschampsia caespitosa (L.) Beauv.	tufted hairgrass
Festuca ovina L.	sheep fescue
Festuca rubra L.	red fescue
Hesperochloa kingii (S. Wats.) Rydb.	King spikefescue
Koeleria cristata (L.) Pers.	prairie junegrass
Poa spp. L.	bluegrass
Poa alpina L.	alpine bluegrass
Poa pattersonii Vasey	Patterson bluegrass
Poa rupicola Nash ex Rydb.	timberline bluegrass
Trisetum spicatum (L.) Richt.	spike trisetum
Graminoids	
Carex albonigra Mack.	blackandwhitescaled sedge
Carex ebenea Rydb.	ebony sedge
Carex elynoides Lilj.	blackroot sedge
Carex obtusata Mackenzie	obtuse sedge
Luzula spicata (L.) DC.	spike woodrush

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[1] *Common names follow Beetle (1970).*

Thilenius, John R., and Dixie R. Smith. 1985. Vegetation and soils of an alpine range in the Absaroka Mountains, Wyoming. USDA Forest Service General Technical Report RM-121, 18 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alpine vegetation was classified into eight community types, described in this report. Soils associated with each community type were classified to soil subgroup level. Environmental factors related to community type distribution were determined.

Keywords: Alpine vegetation, alpine soils, vegetation classification, Carter Mountain

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Rocky
Mountains

Southwest

Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

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National Assessments of Wildlife and Fish: A Technical Framework

Thomas W. Hoekstra and John G. Hof

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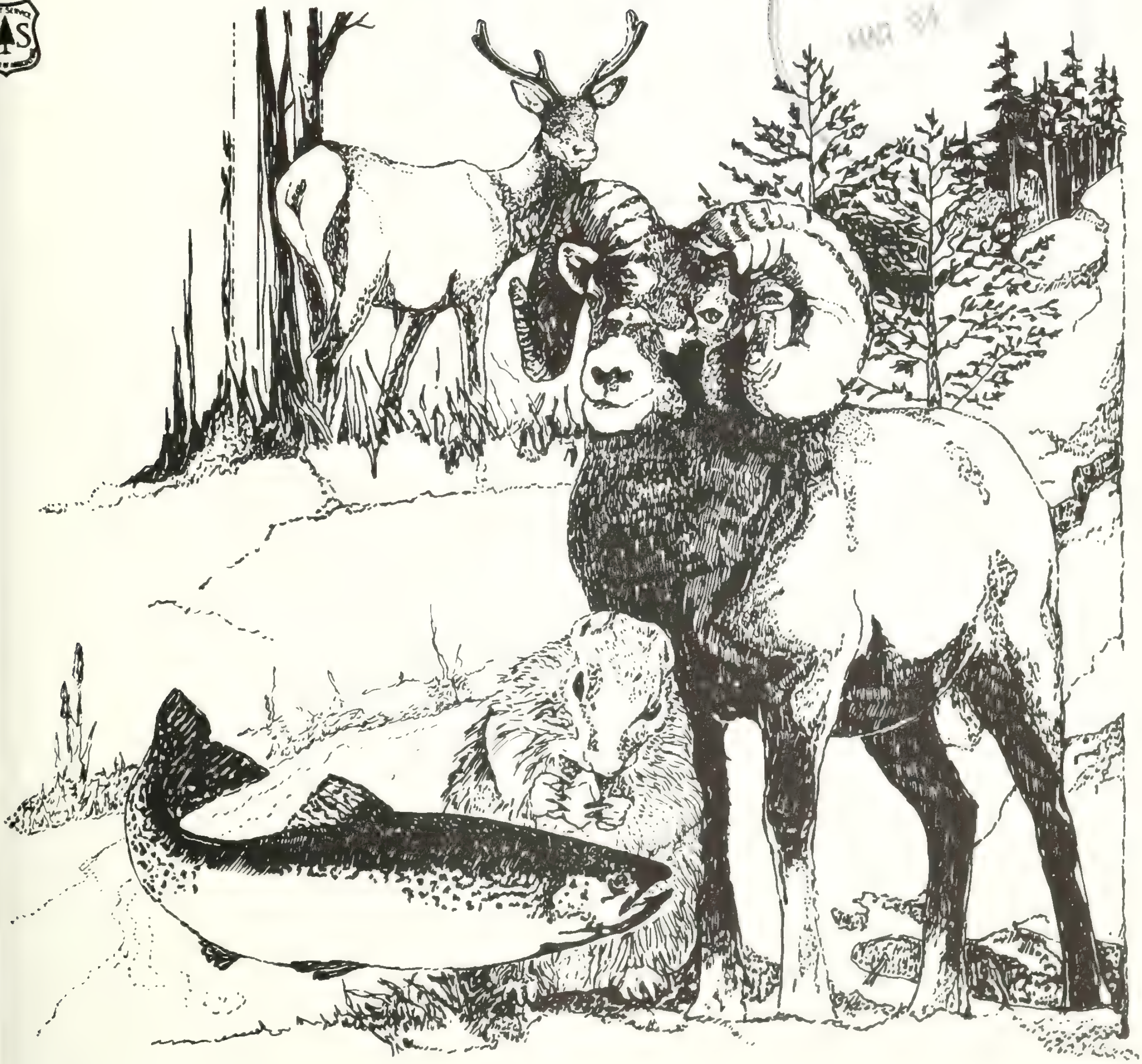

USDA Forest Service
General Technical Report RM-122

October 1

National Assessments of Wildlife and Fish: A Technical Framework

Thomas W. Hoekstra, Principal Wildlife Biologist
and
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Rocky Mountain Forest and Range Experiment Station[1]

Abstract

A national assessment of wildlife and fish can be accomplished by completing three analytical components of the Forest and Rangeland Renewable Resources Planning Act: providing a statement of historical and current land, wildlife, and fish population and habitat production capability; projecting future production and consumption; and identifying opportunities for improving the future renewable resource situation regarding wildlife and fish and their habitats.

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[1] *Headquarters is in Fort Collins, in cooperation with Colorado State University.*

National Assessments of Wildlife and Fish: A Technical Framework

Thomas W. Hoekstra and John G. Hof

Background

National assessments of renewable resources, in- uding wildlife and fish, are required by federal law to escribe the past, present, and future status of renew- ble natural resources. Assessments should satisfy not ly the legal requirement, but also two other objec- ves: to determine the social, economic, and en- ronmental implications of trends in production and onsumption of renewable natural resources; and to resent the findings in a form that would be of use to ublic land management agencies in program develop- ent. This report interprets the law so as to suggest a chnical framework to use as a guide in accomplishing national assessment of wildlife and fish.

The USDA Forest Service, responding to the require- ents of the Forest and Rangeland Renewable esources Planning Act of 1974 (RPA)[2] conducted na- onal assessments in 1975, 1980, and 1984 (USDA orest Service 1977, 1980, 1984). Other national aluations of the wildlife and fish situations have een conducted to address specific issues or concerns bout the resource. A National Appraisal of Fish and ildlife Habitat was conducted by the USDA Soil Con- ervation Service (1980) in response to the Soil and ater Resources Conservation Act of 1977 (RCA).[3] ther evaluations include the National Academy of ciences (1970) report, "Land Use and Wildlife esources," and the Council on Environmental Quality 978) report of a national symposium, "Wildlife and merica."

Additional perspective on the definition, com- onents, difficulties, and successes of conducting a na- onal assessment have come from several other urces: (a) the procedures used to conduct the 1980 PA Assessment of Wildlife and Fish (Schweitzer and ushwa 1978); (b) a progress report (Schweitzer et al. 978); (c) a preliminary evaluation of the 1980 data- ase (Hoekstra et al. 1979); (d) lessons learned in carry- g out the National RPA Assessment of Wildlife and ish (Schweitzer et al. 1980); (e) a report on the role of sessments in monitoring (Hoekstra et al. 1983); and the recommended data base for use in 1989 oekstra et al. 1983).

A national assessment of wildlife and fish can be ac- mplished by completing three technical renewable source oriented components of the RPA: (1) describe d quantify the historical and current status of land ea, wildlife and fish populations, and habitat produc- on capability, (2) project future production and con- mption, and (3) identify opportunities for improving e future renewable resource situation regarding ildlife and fish and their habitats.

Past RPA assessments accomplished some aspects of components 1 and 2 but did not effectively address component 3. To some extent the deficiencies of the RPA and RCA assessments resulted from limited experience in incorporating wildlife and fish resources into production, consumption, and alternative opportunity analyses. Deficiencies continue to exist in available data and analytical techniques for accomplishing these components.

Historical and Current Status

This component most closely follows the conventional perception of how to describe the status of wildlife and fish resources. National and regional summaries of land, resource stocks, and production capabilities have been, and can continue to be, compiled from inventory data files. The continuous forest inventory of the USDA Forest Service (1985) and the national resource inventory of the USDA Soil Conservation Service (1982) are the principal sources of habitat information. State wildlife agencies are the main sources of population and harvest information. The USDI Fish and Wildlife Service is the source of information on migratory and threatened and endangered species populations. However, as Hoekstra et al. (1980) have reported, given the above sources, consistent data for a nationwide assessment of wildlife and fish still exist only in part, even after two RPA Assessments and one RCA Appraisal. Ideally, such data files would include estimates of wildlife and fish species populations, habitat capability, and other renewable resource quantities associated with the same land areas.

A standardized basis for compilation of wildlife and fish habitat information is proposed in table 1. For use in national assessments, land area should be described by resource characteristics and production capability at the county level in 5-year intervals. Ideally, spatial relationships of different ecological conditions should be defined for resources such as wildlife and fish that are dependent upon landscape patterns. Measures of the relative quantities of different ecological conditions as well as their size, shape, and distribution are needed. Descriptions of land area by land use and land cover can be derived for some areas of the nation through the U.S. Geological Survey land use and land cover inventory (Anderson et al. 1976). To the extent that such inventory information is available and compatible with the Forest Service and Soil Conservation Service inventories, it will improve national assessment descriptions of the wildlife and fish habitat situation. Chalk et al. (1985) have recommended a framework for integrating information from Forest Service and Soil Conservation Service multiresource inven-

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[2] *Public Law 94-378, 88 stat. 476.*

[3] *Public Law 95-192, 91 stat. 1407.*

Table 1.—Information on the nation's land and water base needed for a wildlife and fish assessment.

Information	Units
Time Interval	
5-Year or Annual	
Geographic Identification	
State	
County and USGS Hydrologic Cataloging Unit	
Type of Information	
Land Area described by:	Acres
Ownership	
Land Use	
Vegetation Cover Type	
Vegetation Condition Class	
Vegetation Structure Class	
Soil Family	
Current Habitat Capability	
Water Area described by:	Acres
Water System Type	
Water Temperature	
Water Turbidity	
Water Toxicity	
Water Flow	
Water Nutrients	
Geomorphologic Factors	

tories for use in national assessments and appraisals of wildlife and fish.

Current actual and potential habitat capability information in table 1 describes land capability in terms of productivity and condition of wildlife and fish resource stock. Habitat capability estimates are calculated from information on the current quantities of habitat, populations, and land management actions by such methods as multivariate statistical models (Capen 1981), pattern recognition models (Williams et al. 1977), habitat evaluation procedures (U.S. Department of Interior, Fish and Wildlife Service 1980), and wildlife habitat relationships (Nelson and Salwasser 1982). Current habitat capability is defined by the current population level of a species in its current habitat on a particular land unit. Potential wildlife and fish habitat capability is defined by the population level of a species that the habitat should be capable of producing under a specific land management action(s) on a particular land unit for a specified time period. Ideally, current and potential habitat capability would be calculated as the estimated number of animals produced per unit of land (e.g., kg/ha). The need to consider interspecific interactions (e.g., competition or production) is recognized, and such interactions are considered to be implicitly accounted for in current and potential habitat capability (Flather and Hoekstra, in press).

A standardized basis for compilation of information on wildlife and fish populations, harvest, and consumptive use is proposed in table 2. An information base for both habitat and populations (size and use) on a common geographic basis is essential for both compilation and predictive purposes. For most species, indexes of population and/or numbers of animals harvested serve as surrogate measures for the more desirable population size estimates as these are frequently the onl measures available. Because state wildlife and fis agencies typically estimate size and use annually, it i expedient to develop the RPA information base in tha manner. The information in tables 1 and 2 is useful fo describing the current or historical situation. It tell where we are and how we might have gotten there.

Consumption and Inventory Projections

The second component, which calls for a projectio of the consumption and inventories of renewable resources into the future, is a substantial extensio beyond the first.

Consumption Projections

Over the years, a number of studies have attempte to project recreation consumption levels (including recreational consumption of wildlife and fish) for specifi regions and the entire nation (e.g., Kalter and Goss 1969, Cichetti et al. 1969, Adams et al. 1973, Wege 1979, Hof and Kaiser 1983). It is generally agreed thes are not true demand projections in the economic sens They are projections of actual consumption levels tha are affected by both supply and demand factors.

For resources provided through a market, a trad tional competitive market structure would be appropr ate for projecting consumption. In a competitiv market, pricing serves to bring demand and supply int an "equilibrium." An excellent example of this sort c projection model is the Timber Assessment Mark Model (Adams and Haynes 1980).

In general, consumption of wildlife and fish (especia ly recreational consumption) is not governed by market, so a market "equilibrium" is probably not a appropriate concept for such projections. For such non market goods, Hof and Kaiser (1983) recommend th following consumption function for use in projections:

$$Q_c = F(P,X_i,Q_p) \quad [1$$

where

Q_c = the quantity of wildlife and fish resources actually consumed
P = a price surrogate, e.g., travel costs or tim costs
X_i = the traditional "demand shifters," such a population (human), income, and age
Q_p = the quantity provided (wildlife and fish r sources available).

They discuss the Qc as a "disequilibrium" betwee supply and demand factors. In order to project Q_c, t function F must first be estimated (generally regresse based on historic (time series) or cross-sectional dat Then, by substituting projected levels of P, X_i, and Q_p, projected level of Q_c can be calculated. This, of cours assumes that the function F is unchanging througho ble 2.—Information on the nation's wildlife and fish populations and their use needed for a wildlife and fish assessment.

me Interval
Annual

eographic Identification
State
Wildlife and Fish Administrative Region (Multicounty)
County and USGS Hydrologic Cataloging Unit

pe of Information

	Units
Species Population Size	No./Area or Index
Species Harvest	No./Area
Consumptive Users (by Species)	No. and Effort/Area

e projection time period. It should also be noted that tle is gained if projection of the P, X_i, and Q_p variables in fact, as difficult as projecting the Q_c in the first ace. A simply alternative is to utilize the time trend of , or to simply regress Q_c against population levels and en apply population projections alone.

Two important points need to be stressed concerning nsumption projections. First, such projections are, in sence, only extrapolations of past trends. They do not cessarily represent a desirable level of consumption. us, it is not appropriate to project consumption and en treat it as a "target" level of "demand" to be met. an extreme analogy, this would be like predicting the inent extinction of a particular species, such as blue hales, and then working diligently to promote that prediction. Wildlife and fish consumption projections ould only be used for predicting large-scale overuse of rticular wildlife and fish resources.

Second, strong evidence is available (Kalter and sse 1969, Cichetti et al. 1969, Hof and Kaiser 1983) to ggest that the Q_p variable in equation [1] is very important in determining the Q_c. This implies that if wildlife d fish resource production is increased in an attempt "meet" a given set of consumption projections (in the pe of reducing overuse), then this alone will probably ult in consumption levels higher than would have occurred otherwise. This is hardly a shocking conclusion; f resource "supplies" are in any way restricting or in- iting consumption, then it is obvious that increasing pplies" will cause increased consumption. However, ts easy to forget this logic when attempting to obviate ge-scale overuse problems.

entory Projections

urrent and historical inventories of wildlife and fish pulations and their habitats provide information on t trends in resource quantities. Analysis of factors h as land use that are correlated with these trends assist in making projections of future inventories. h projections are generally based on three classes of umptions: (1) ecological assumptions concerning land ability, population biology, and management actions; (2) economic assumptions on resource markets, resource harvests, income, and employment; and (3) social structure assumptions defining institutional variables.

For resources provided through the public sector, as from the National Forests or lands administered by the Bureau of Land Management, estimates of future inventories can be obtained from land and resource management planning activities. This is generally not true for private lands. To be useful, estimates of future resource inventories on private lands must account for differences in ownership objectives.

Models based on the set of ecological assumptions have been developed to project future wildlife and fish populations based on current numbers, sex and age ratios, natality, harvest, and mortality rates. Other models have projected future wildlife and fish populations based on relationships to habitat (Hawkes et al. 1983). Ideally, population inventory projections would be made using both population and habitat parameters; however, inadequate data and analytical tools impose severe limitations.

Prediction of wildlife and fish populations based on population size, structure, and dynamics is difficult, and few techniques exist that can be applied to produce accurate and precise information, except for use in very local situations. Many species do not lend themselves easily to direct population estimation due to mobility and behavioral characteristics (Miller 1984). Potential population estimates based on size, structure, and dynamic attributes of species populations and some assumed environmental conditions lack an explicitly stated relationship to current habitats and, therefore, are difficult to relate to land management activities.

Predictions of wildlife and fish populations can be classified as indirect or direct, depending upon the kind of wildlife habitat relationships model used. In the case of indirect population estimates, the habitat relationship models estimate the potential suitability of the habitat to support a species population. Population levels are not a product of the model and suitability indexes cannot be reliably or consistently converted to population levels. The more direct approach uses multivariate statistical methods (Capen 1981). In this approach, measured populations are correlated with inventoried environmental variables to establish the relationship between habitat and populations (Kitchings and Klopatek 1982)[4]. The multivariate statistical models developed by Kitchings and Klopatek are a prototype for more detailed models being developed for the 1989 Assessment.

The 1989 assessment models are based on the land and water base descriptions in table 1 and the population information in table 2. Counties are the sample unit, but results are reported by ecological and/or Forest Service administrative regions (multistate). Future populations can be predicted based on different scenarios about changes in the correlated land and water base descriptor variables estimated exogenously in area projection, and other resource inventory projection.

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[4] *Kitchings, Thomas, and Jeffrey Klopatek. 1982. A regional approach to prediction of distribution and abundance of animal species. Final Report for Interagency Agreement (IAG 40-1105-80), ORNL, Environmental Sciences Division and USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 72 p + appendix. Mimeo.*

Econometric area projection models that include the economic and social assumptions for forestland, rangeland, and cropland are being developed with the vegetation type and structure variables given in table 1 (Alig and Knight 1983). Such area projection models estimate likely future acreages through assumptions of how prices of market resources, population levels, etc., will change in the future; they are based on historical relationships between these variables and land use. Wildlife inventory projections developed in conjunction with area projections are restricted to the limits of their relationship in historical data. Scenarios that might be of interest, but are outside past experience, are not analyzable.

To perform analyses estimating multiple resource production, it is necessary that the analyses of all renewable resources be based on the same units of land and the same set of potential management actions (Joyce 1983). There is currently no standardized multiresource definition of management actions from which individual resource production responses could be estimated. Few production response relationships between management actions and wildlife and fish resources have been quantified, and fewer still have been quantified for multiple resources (which include wildlife and fish). Fortunately, in a specific ecological situation, only a limited number of different management actions are typically carried out; this makes the framework less complex.

Timber inventory projection models provide a means by which wildlife populations primarily associated with forestland can be projected. Such inventory projection models, which incorporate land area and timber stand characteristics, can be linked to wildlife models that contain the same management intensification variables. Like the area projection models, this approach is restricted by the relationships available in historical data.

Opportunities for Improving the Future Renewable Resource Situation

To discuss this third technical component for an assessment of wildife and fish, it is necessary to define the economic concept of technical efficiency (e.g., Henderson and Quandt 1971). A production system can be said to be in a technically efficient state when, given the inputs available, no more of any output can be produced without a resultant reduction in the production of some other output or outputs. Production tradeoffs can be defined only in the context of technical efficiency, since in the absence of such efficiency, more of any given output can be produced with no tradeoff in other outputs. Also, technical efficiency is an important concept in discussing "opportunities to improve the renewable resource situation" because most of these opportunities involve a movement towards more technically efficient ways to manage renewable resources.

To analyze technically efficient production tradeoffs or potential improvements in technical efficiency, some means is necessary to sort out all the inefficient ways of managing renewable resources from the more efficient ways. One very popular approach to doing this is linear programming (LP). Again, its purpose in the context of this report is to sort through a large number of management actions that might be applied to arrive at a management configuration (model solution) that maximizes or minimizes some objective function, such as maximum output, minimum cost, and maximum present net worth.

A number of papers describe mathematical programming procedures that are appropriate for generating multiresource production possibilities (e.g., D'Aquino 1974, Ashton et al. 1980, Kent 1980).[5] In the USDA Forest Service, a model called FORPLAN (Johnson et al 1980)[6] is used for this purpose at the National Forest level. Each alternative opportunity generated simply includes the vector of multiresource outputs that can be produced at an associated joint cost, and the economic benefits associated with those outputs. Recognizing tha the Forest Service is a multilevel agency (Forest, Region and National levels), planning future opportunitie necessarily occurs at all three levels. Wong (1980) an Hof et al. (1983) propose a multilevel optimizatio system with local, regional, and national level models.

Figure 1 depicts the linear programming matrix of very simple version of a national model. A regiona model would be structured similarly, with forests r placing the regions in figure 1. In this example, only tw regions, two alternatives, three products, and one tim period are included. Expansion beyond the dimension of this simple example is straightforward. In figure 1, X through X_4 are 0-1 variables representing selection o rejection of an alternative output vector (A_{ij}) with ass ciated joint cost (F_i; i = 1, 4) for a given region. For exan ple, X_1 represents selection or rejection of the entire ou put vector $A_{1,1}$; $A_{2,1}$; $A_{3,1}$ in Region 1. Rows 5 through 7 s national "targets" on the 3 outputs (T, W, F). Row places a budget constraint on the selection of alte natives, and row 8 is the objective function to be ma imized. All of the matrix below the objective functio row constrains the X_1 through X_4 so that each of them between 0 and 1, and so that only 1 alternative can selected for each region (ignoring non-integer solutions

The principal advantage of a multilevel optimizati such as this is that the detail and high resolution local-level analyses are preserved, but some nation discretionary choice is still allowed. The implied n tional model reflects a great deal of detailed productio analysis, but is of very workable size and complexit Also, any national model solution is automatically d aggregatable to (and consistent with) local manageme plans. The principal shortcoming of a multilevel c timization approach is that limiting the national analy to a finite number of discrete choices may overlo desirable options and thus lead to suboptimization.

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[5] *Kent, Brian M. 1980. Introduction to linear programming. 63 Department of Agriculture, Land Management Planning, Syste Application Unit, Fort Collins, Colo.*

[6] *Johnson K. Norman, Daniel B. Jones, and Brian M. Kent. 19 Forest planning model (FORPLAN) user's guide and operati manual draft. 258 p. U.S. Department of Agriculture, Land Mana ment Planning, Fort Collins, Colo.*

	Region 1		Region 2		Outputs				
	X_1	X_2	X_3	X_4	T	W	F	Type	RHS
mber	$A_{1,1}$	$A_{1,2}$	$A_{1,3}$	$A_{1,4}$	-1			=	$0 = K_1$
ildlife	$A_{2,1}$	$A_{2,2}$	$A_{2,3}$	$A_{2,4}$		-1		=	$0 = K_2$
orage	$A_{3,1}$	$A_{3,2}$	$A_{3,3}$	$A_{3,4}$			-1	=	$0 = K_3$
udget	C_1	C_2	C_3	C_4				$\leq$	K_4
					1			$\geq$	K_5
						1		$\geq$	K_6
							1	$\geq$	K_7
bj. Fun.	$-F_1$	$-F_2$	$-F_3$	$-F_4$	F_5	F_6	F_7	–	MAX
– 1	1	1						=	1
odel									
Constraints			1	1				=	1

gure 1.—A simple national model, where the X_1 through X_4 are 0–1 variables representing selection or rejection of an output vector $A_{1,1}$ through $A_{i,4}$ (i = 1,3), respectively. The F_i are the objective function coefficients, and K_1 through K_7 are right-hand sides (RHS).

Conclusion

National assessments of wildlife and fish as carried ut by the USDA Forest Service are integral parts of na- onal resource planning. In addition to the traditional nalyses of the status and condition of wildlife and fish sources, national assessments should project inven- ries and use and analyze opportunities and implica- ons for changing the future resource situation.

The technical components for national assessments iscussed in this report are intended to provide uidance to wildlife biologists on the data needs and nalysis procedures useful in developing the mandated eriodic reports to Congress. Consistent information is ghly desirable for the relatively small number of data ems used in national assessments. National sessments are one means of providing comprehensive ports about the wildlife and fish resources and of ex- nining the production tradeoffs that can be made in e future regarding the national resources produced on e nation's forestland and rangeland.

Literature Cited

dams, R. L., R. C. Lewis, and B. H. Drake. 1973. Outdoor recreation, a legacy for America: Appendix "a" an economic analysis. Bureau of Outdoor Recreation, Washington, D.C.

dams, D. A., and R. W. Haynes. 1980. The 1980 softwood timber assessment market model: structure, projections, and policy simulations. Forest Science Monograph No. 22.

lig, Ralph J., and Herbert Knight. 1983. Forest acreage model for the U.S. Southeast. p. 242–246. *In* Proceedings of an international conference on renewable resource inventories for monitoring changes and trends. [Corvallis, Oreg., August 15–19, 1983]. 737 p. John F. Bell and Toby Atterbury, editors. Oregon State University, College of Forestry, Corvallis.

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper 964. 28 p. U.S. Government Printing Office. Washington, D.C.

Ashton, Peter G., James B. Pickens, Coryell Ohlander, and Bruce Benninghoff. 1980. Many resources, many uses: A system analysis approach to renewable resource development. Water Resources Bulletin 16:738–744.

Capen, David E., editor. 1981. The use of multivariate statistics in studies of wildlife habitat. USDA Forest Service General Technical Report RM-87, 249 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Chalk, David E., Stephen A. Miller, and Thomas W. Hoekstra. 1985. Multiresource inventories: Integrating information on wildlife resources. Wildlife Society Bulletin 12:357–364.

Cichetti, Charles J., Joseph J. Seneca, and Paul Davidson. 1969. The demand and supply of outdoor recreation. 301 p. Bureau of Economic Research, Rutgers—The State University, New Brunswick, N.J.

Council on Environmental Quality. 1978. Wildlife and America. 532 p. Howard P. Browkaw, editor. U.S. Government Printing Office, Washington, D.C.

D'Aquino, Sandy A. 1974. Optimum allocation of resources: A programming approach. Journal of Range Management 27:228–233.

Flather, Curtis H., and Thomas W. Hoekstra. 1985. Evaluating population-habitat models using ecological theory. Wildlife Society Bulletin 13:121–130.

Hawkes, Clifford L., David E. Chalk, Thomas W. Hoekstra, and Curtis H. Flather. 1983. Prediction of wildlife and fish resources for national assessments and appraisals. USDA Forest Service General Technical Report, RM-100, 21 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Henderson, James M., and Richard E. Quandt. 1971. Microeconomic theory: A mathematical approach. 431 p. McGraw-Hill, New York, N.Y.

Hoekstra, Thomas W., Dennis L. Schweitzer, Stanley H. Anderson, Robert B. Barnes, and Charles T. Cushwa. 1979. Preliminary evaluation of a national wildlife and fish data base. Transactions of the North American Wildlife and Natural Resources Conference 44:380–390.

Hoekstra, Thomas W., David E. Chalk, Clifford L. Hawkes, and Stephen A. Miller. 1983. Monitoring regional wildlife and fish habitats and populations for national assessments and appraisals. Transactions of the North American Wildlife and Natural Resource Conference 48:308–314.

Hoekstra, Thomas W., Michael P. Farrell, Curtis H. Flather, and Clifford L. Hawkes. 1983. Wildlife and fish data base for the 1989 national RPA assessment. p. 75–83. *In* Proceedings of national workshop on computer uses in fish and wildlife programs. Virginia Polytechnic Institute and State University. Blacksburg, Va. 327 p.

Hof, John G., Linda A. Joyce, Gregory S. Alward, and Thomas W. Hoekstra. 1983. Multilevel analysis of forest and rangeland resources. p. 43–49. *In* Wagstaff, F. ed. Range economics symposium and workshop proceedings. [Salt Lake City, Utah, August 31–September 2, 1982.] General Technical Report INT–149, 151 p. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Hof, John G., and H. Fred Kaiser. 1983. Long term outdoor recreation participation projections for public land management agencies. Journal of Leisure Research 15(1):1–14.

Joyce, Linda A. 1983. Multiresource production at the regional level. p. 50–56. *In* Wagstaff, F. ed. Range economics symposium and workshop proceedings. [Salt Lake City, Utah, August 31–September 2, 1982]. General Technical Report INT–149, 151 p. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Kalter, Robert J., and Lois E. Gosse. 1969. Outdoor recreation in New York state: projections of demand, economic value, and pricing effects. Cornell University Special Series. 57 p. Ithaca, N.Y.

Miller, Stephen A. 1984. Estimation of animal production numbers for national assessments and appraisals. USDA Forest Service General Technical Report RM–105, 23 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Nelson, Robert D., and Harold Salwasser. 1982. The Forest Service and fish habitat relationships program. Transactions of the North American Wildlife and Natural Resources Conference 47:174–183

National Academy of Sciences. 1970. Land use and wildlife resources. 262 p. Washington, D.C.

Schweitzer, Dennis L., and Charles T. Cushwa. 1978. A national assessment of wildlife and fish. Wildlife Society Bulletin 6(3):148–152.

Schweitzer, Dennis L., Charles T. Cushwa, and Thomas W. Hoekstra. 1978. The 1979 national assessment of wildlife and fish: A progress report. Transactions of the North American Wildlife and Natural Resources Conference 43:266–273.

Schweitzer, Dennis L., Thomas W. Hoekstra, and Charles T. Cushwa. 1980. Lessons from past national assessments of wildlife and fish–information and coordination needs for the future. Transactions of the North American Wildlife and Natural Resources Conference 45:147–155.

U.S. Department of Agriculture, Forest Service. 197 The nation's renewable resources–an assessmen 1975. Forest Resources Report 21. 243 p. Washingto D.C.

U.S. Department of Agriculture, Forest Service. 198 An assessment of the forest and rangeland situatio in the United States. Forest Resources Report 35 631 p. Washington, D.C.

U.S. Department of Agriculture, Forest Service. 198 Forest Sercice resource inventory: an overview. 29 Forest Resource Economics Research Staff. Wash ington, D.C.

U.S. Department of Agriculture, Forest Service. 198 America's Renewable Resources: A supplement to t 1979 Assessment of the Forest and Rangeland Situ tion in the United States. FS–386. 84 p. Washingto D.C.

U.S. Department of Agriculture, Soil Conservation Ser ice. 1980. Appraisal 1980. (Review Draft Part I Washington, D.C.

U.S. Department of Agriculture, Soil Conservation Ser ice. 1982. Basic Statistics. 1977 National Resource I ventory, Statistical Bulletin No. 686. 267 p. Washin ton, D.C.

U.S. Department of the Interior, Fish and Wildlife Ser ice. 1980. Habitat evaluation procedures (HEP). ES 102. Division of Ecological Services, Washington, D.C

Wegert, William E. 1979. Demand analysis and proje tions of use for hunting and fishing opportunities. M. thesis. 70 p. Colorado State University, Fort Colli Colo.

Williams, G. L., K. R. Russell, and W. K. Seitz. 19 Pattern recognition as a tool in the ecological analy of habitat. p. 521–531. *In* Classification, invento and analysis of fish and wildlife habitat—The p ceedings of a national symposium. [Phoenix, Ari January 24–27, 1977.] U.S. Fish and Wildlife Servi Office of Biological Service, FWS/OBS–78/76, Wa ington, D.C. 604 p.

Wong, Cory P. 1980. A multilevel approach to the For Service planning process. M.S. thesis. 79 p. Colora State University, Fort Collins, Colo.

Hoekstra, Thomas W., and John G. Hof. 198~~4~~5. National assessments of wildlife and fish: A technical framework. USDA Forest Service General Technical Reports RM-122, 6 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

A national assessment of wildlife and fish can be accomplished by completing three analytical components of the Forest and Rangeland Renewable Resources Planning Act: providing a statement of historical and current land, wildlife, and fish population and habitat production capability; projecting future production and consumption; and identifying opportunities for improving the future renewable resource situation regarding wildlife and fish and their habitats.

Keywords: National assessments, national appraisals, renewable resource inventories, resource use projections, opportunities analysis, trade-off analysis

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky
Mountains

Southwest

Great
Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

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Major Habitat Types, Community Types, and Plant Communities in the Rocky Mountains

Robert R. Alexander

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Abstract

Habitat types, community types, and plant communities in the Rocky Mountains in which interior *Pinus ponderosa*, interior *Pseudotsuga menziesii*, interior *Abies concolor*, *Picea pungens*, *Populus tremuloides*, *Pinus contorta*, *Picea engelmannii*, and *Abies lasiocarpa* occur are tabulated. Included are the name, location, site, successional status, principal tree and understory associates, and the authority.

USDA Forest Service
General Technical Report RM-123

November 1

Major Habitat Types, Community Types, and Plant Communities in the Rocky Mountains

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Rocky Mountain Forest and Range Experiment Station[1]

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Major Habitat Types, Community Types, and Plant Communities in the Rocky Mountains

Robert R. Alexander

Because terminology in ecology is not uniformly used understood, the terms and concepts used in this per are defined below.

'Climax" vegetation is that which has attained a ady state with its environment; species of climax getation successfully maintain their population sizes, hough their exact locations may be dynamic in ace. The classification of climax vegetation used in is paper was first proposed by Tansley (1935). ubenmire (1968), Hoffman and Alexander (1976), d Pfister et al. (1977) further elaborated on the finition, usage, and limitations. "Primary climaxes" velop where recurring disturbance does not influce the structure or composition of the vegetation. limatic climax" vegetation develops on gentle land or plains topography with well-developed soils iginating in place. Topography and soil supporting max vegetation in mountainous regions are necesrily different from that of plains regions. Where soils topography exert sufficient influence to produce lf-perpetuating vegetation distinct from the climatic max, the terms "edaphic climax" and "topographic max," respectively, are used to describe the steadyte vegetation. Where special topographic conditions o favor the development of edaphic conditions tinct from the normal, the term "topo-edaphic max" is often used to describe the steady-state getation.

Where recurring disturbance, such as grazing, chanical scarification, or fire, exerts a predominant luence on the composition or structure of steadyte vegetation, the term "disclimax" is used. In this e, the current vegetation may be developing into a ferent community (secondary climax) than the mary climax; however, in most forests, primary and ondary climaxes are the same. "Seral" vegetation that which has not attained a steady state; current ulations of some species are being replaced by ers. In some instances, trends toward the "climax" etation can be identified, in others these trends are evident, and in still others the vegetation may not ert to primary climax.

Habitat type" is the basic unit in classifying lands ed on potential (climax) natural vegetation. A itat type represents, collectively, all parts of the dscape that support, or have the potential of supting, the same climax vegetation. The climax etation upon which the classification is based is ed a "plant association". The first level of the sification is the "series," which is the grouping of plant associations having the same overstory nax) dominants. For example, all habitat types with us *ponderosa* as the potential climax dominant are grouped into the *Pinus ponderosa* series. The series is more than an artificial grouping of habitat types using the potential climax overstory dominant as the convenient thread of continuity. There is an ecologic basis for grouping habitat types into series. For example, *Pinus ponderosa* occupies areas that are warmer and drier than areas where *Pseudotsuga menziesii* is climax. Continuing higher into the mountains in the central and southern Rockies, *Abies concolor*, *Picea pungens*, *Populus tremuloides*, *Pinus contorta*, *Picea engelmannii*, and *Abies lasiocarpa* successively become the dominant species. It is assumed that self-perpetuating populations of these dominant trees are related to the macroclimate, whereas the undergrowth vegetation is related more to microclimate and soils.

Habitat types within a series are distinguished on the basis of undergrowth vegetation unions, which are the second level of classification and the smallest structural unit of the vegetation. Each "union" consists of a population of one or more species that exhibit similar microenvironmental requirements. The species comprising the union may vary from place to place, but the variation is within narrow limits. A given species may occur in more than one union, but frequency and occurrence are different between unions. Unions are usually regional; their composition changes in different regions.

Much of the forest land in the West has been disturbed by fire, logging, grazing, insect and disease outbreaks, etc., for many years. Because of these disturbances, not all of the land area currently supports climax vegetation. It is possible that vegetation over much of the area of a habitat type will never attain climax status. While it is important to consider land units in terms of their potential climax status, it is not always possible to identify the climax plant association. The term "community type" has been used to identify vegetation which may be climax, but about which there is uncertainty. Community types have one or more overstory dominants and an undergrowth union. The undergrowth may be the climax union, but the overstory dominants are usually long-lived seral vegetation that may be self-perpetuating because of repeated disturbance that prevents or slows down the succession to climax vegetation.

"Plant communities" are used here to identify vegetation that was classified by methodology other than that used for habitat types. Plant communities may later be found to be plant associations or seral vegetation. They may be used, therefore, to identify habitat types or community types.

Tables A1 through A8 in the appendix list the identified habitat types, community types, and plant communities where interior *Pinus ponderosa*, interior *Pseudotsuga menziesii*, interior *Abies concolor*, *Picea pungens*, *Populus tremuloides*, *Pinus contorta*, *Picea engelmannii*, and *Abies lasiocarpa* are the major climax, co-climax, minor climax, or major seral species. Also included are location, site, principal tree and understory associates, and the authority for the classification.

There are some items in the tables that need further clarification:

1. The description of the site, i.e., warm dry, cool dry, etc., refers only to the series and location and, therefore, is relative. Obviously a warm dry *Pinus ponderosa* site is not the same as a warm dry *Abies lasiocarpa* site. Moreover, a warm dry site in Arizona may not be the same as a warm dry site in Idaho even within a series.
2. In those habitat types where more than one phase is recognized, only the typical phase is listed. "Phase" is a subdivision of a habitat type representing a characteristic variation in climax vegetations and environmental conditions, respectively.
3. A number of communities have been lumped together that the cited authority recognized as different. For example, Mueggler and Campbell (1982) identified the following four community types:
    - a) *Populus tremuloides/Amelanchier alnifolia-Pachistima myrsinites*
    - b) *Populus tremuloides/Amelanchier alnifolia-Symphoricarpos oreophilus*
    - c) *Populus tremuloides/Amelanchier alnifolia-Spiraea betulifolia*
    - d) *Populus tremuloides/Amelanchier alnifolia-Calamagrostis rubescens*

The author lumped these into a *P. tremuloides/A. alnifolia* community type to reduce the number of communities that must be dealt with.

References Cited

Published

Alexander, Billy G., Jr., Frank Ronco, Jr., E. Lee Fitzhugh, and John A. Ludwig. 1984a. A classification of forest habitat types on the Lincoln National Forest, New Mexico. USDA Forest Service General Technical Report RM–104, 29 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Billy G., Jr., Frank Ronco, Jr., Alan S. White, and John A. Ludwig. 1984b. Douglas-fir habitat types of northern Arizona. USDA Forest Service General Technical Report RM–108, 13 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Daubenmire, R. 1968. Plant communities: A textbook of plant synecology. 300 p. Harper and Row, New York, N.Y.

Daubenmire, R., and Jean B. Daubenmire. 1968. Forest vegetation of eastern Washington and northern Idaho. Technical Bulletin 60, 104 p. Washington Agricultural Experiment Station, Washington State University, Pullman.

Hanks, Jess P., E. Lee Fitzhugh, and Sharon R. Hanks. 1983. A habitat type classification system for ponderosa pine forests of northern Arizona. USDA Forest Service General Technical Report RM–97, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hess, Karl. 1981. Phyto-edaphic study of habitat types of the Arapaho and Roosevelt National Forests. Ph.D. dissertation, 558 p. Colorado State University, Fort Collins.

Hoffman, George R., and Robert R. Alexander. 1976. Forest vegetation of the Bighorn Mountains, Wyoming: A habitat type classification. USDA Forest Service Research Paper RM–170, 38 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hoffman, George R., and Robert R. Alexander. 1980. Forest vegetation of the Routt National Forest in northwestern Colorado: A habitat type classification. USDA Forest Service Research Paper RM–221, 41 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hoffman, George R., and Robert R. Alexander. 1983. Forest vegetation of the White River National Forest in western Colorado: A habitat type classification. USDA Forest Service Research Paper RM–249, 36 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Mauk, Donald L., and Jan A. Henderson. 1984. Forest habitat types of northern Utah. USDA Forest Service General Technical Report, INT–170, 89 p. Intermountain Forest and Range Experiment Station, Ogden, Utah

Moir, W. H. 1969. The lodgepole pine zone in Colorado. American Midland Naturalist 81:87–98.

Moir, William H., and John A. Ludwig. 1979. A classification of spruce-fir and mixed conifer habitat types of Arizona and New Mexico. USDA Forest Service Research Paper RM–207, 47 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Mueggler, Walter F., and Robert B. Campbell. 1982. Aspen community types on the Caribou and Targhee National Forests in southeastern Idaho. USDA Forest Service Research Paper INT–294, 32 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Pfister, Robert D. 1972. Vegetation and soils in the subalpine forests of Utah. Ph.D. dissertation, Washington State University, Pullman. Dissertation Abstract 33(06):98.

Pfister, Robert D., Bernard L. Kovalchik, Stephen F. Arno, and Richard C. Presby. 1977. Forest habitat types of Montana. USDA Forest Service General Technical Report INT–34, 174 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

ele, Robert, Robert D. Pfister, Russell A. Ryker, and ay A. Kittams. 1981. Forest habitat types of central daho. USDA Forest Service General Technical eport INT–114, 138 p. Intermountain Forest and ange Experiment Station, and Intermountain egion, Ogden, Utah.

ele, Robert, Stephen V. Cooper, David M. Ondov, avid W. Roberts, and Robert D. Pfister. 1983. Forest abitat types of eastern Idaho-western Wyoming. SDA Forest Service General Technical Report NT–144, 122 p. Intermountain Forest and Range Exeriment Station, and Intermountain Region, Ogden, tah.

nsley, A. G. 1935. The use and abuse of vegetational oncepts and terms. Ecology 16:284–307.

rsing, John M., and Robert R. Alexander. 1975. orest habitat types on the Medicine Bow National orest, southeastern Wyoming: Preliminary report. SDA Forest Service General Technical Report M–12, 11 p. Rocky Mountain Forest and Range Exeriment Station, Fort Collins, Colo.

ungblood, Andrew P., and Walter F. Mueggler. 1981. spen community types on the Bridger-Teton National Forest in western Wyoming. USDA Forest ervice Research Paper INT–272, 34 p. Intermounain Forest and Range Experiment Station, Ogden, tah.

published

xander, Billy G., Jr., E. Lee Fitzhugh, Frank Ronco, r., and John A. Ludwig. 1984c. A classification of orest habitats of the Cibola National Forest, New exico. USDA Forest Service [Mimeo of manuscript n preparation] [Report], 120 p. Rocky Mountain orest and Range Experiment Station, Fort Collins, olo.

oper, Steven, Kenneth Neiman, and Robert Steele. 983. Forest habitat types of northern Idaho. USDA orest Service [Mimeo of manuscript in preparation] eport], 210 p. Intermountain Forest and Range Exeriment Station, Ogden, Utah, and Northern Rocky ountain Region, Missoula, Mont.

DeVelice, Robert L., John A. Ludwig, William H. Moir, and Frank Ronco, Jr. 1984. A classification of forest habitat types in northern New Mexico and southern Colorado. USDA Forest Service [Mimeo of manuscript in preparation] [Report], 173 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Fitzhugh, E. Lee, William H. Moir, John A. Ludwig, and Frank Ronco, Jr. 1984. Forest habitat types in the Apache, Gila, and part of the Cibola National Forests. USDA Forest Service [Mimeo of manuscript in preparation] [Report], 145 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hess, Karl, and Clinton H. Wasser. 1982. Grassland, shrubland and forestland habitat types of the White River-Arapaho National Forest. USDA Forest Service [Mimeo] Report, 335 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hoffman, George R. 1984. Forest vegetation of the Black Hills and Bearlodge Mountains of South Dakota and Wyoming: A habitat type classification. Personal correspondence. On file at USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Komarkova, Vera. 1984. Habitat types on selected parts of the Gunnison and Uncompahgre National Forests. USDA Forest Service [Mimeo] Report, 254 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Steen, Ordell, and Ralph Dix. 1974. A preliminary classification of Colorado subalpine forests. [Mimeo] Report, 10 p. Colorado State University, Department of Biology and Plant Pathology, Fort Collins, Colo. (On file at USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.).

Youngblood, Andrew P. 1984. Coniferous forest habitat types of central and southern Utah. USDA Forest Service [Mimeo of manuscript in preparation] [Report], 302 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Table A1.—Habitat types, community types, and plant communities in which interior *Pinus ponderosa* is climax, co-climax, minor climax, or seral.

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. ponderosa***	**Principal tree associates**	**Principal understory species**	**Authority**
			***Pinus ponderosa* series**			
Pinus ponderosa / *Arctostaphylos patula* H.T.	Mountains of southern Utah	Warm dry	Climax	*Pinus flexilis* *Juniperus scopulorum*	*A. patula* *Quercus gambelii* *Purshia tridentata* *Berberis repens*	Youngblood 1 4
Pinus ponderosa / *Arctostaphylos pungens* H.T.,C.T.	Mountains of northern and central Arizona	Warm dry	Climax	Usually pure stands	*A. pungens* *Quercus* spp. *Bouteloua gracilis* *Muhlenbergia virescens* *A. patula*	Fitzhugh et al 1984 Hanks et al. 1 3
Pinus ponderosa / *Arctostaphylos uva-ursi* H.T.	Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming; mountains of northern New Mexico and southern Colorado	Warm dry	Climax	Usually pure stands (SD,WY) *Pseudotsuga menziesii* (CO,NM)	*A. uva-ursi* *Carex* spp. *Lathyrus ochroleucus* *Festuca arizonica* (CO,NM) *Muhlenbergia montana* (CO,NM)	DeVelice et al 1984 Hoffman 1984
Pinus ponderosa / *Artemisia nova* H.T. [*P. ponderosa* / *Artemisia arbuscula* H.T.]	Mountains of southern Utah and southern Colorado	Warm dry	Climax	*J. scopulorum* *Pinus edulis*	*A. nova* *A. arbuscula* *Chrysothamnus viscidiflorus* *Tetradymia canescens* *Q. gambelii*	DeVelice et al 1984 Youngblood 1 4
Pinus ponderosa / *Cercocarpus ledifolius* H.T.	Mountains of central and southern Utah	Warm dry	Climax	*J. scopulorum* *P. edulis*	*C. ledifolius* *Juniperus* spp. *Q. gambelii* *Symphoricarpos oreophilus* *Artemisia tridentata*	Youngblood 1 4
Pinus ponderosa / *Cercocarpus montanus* H.T.	Front Range, north-central Colorado	Warm very dry	Climax	Usually pure stands	*C. montanus* *Artemisia frigida* *Opuntia polyacantha* *Carex rossii* *Geranium fremontii*	Hess 1981
Pinus ponderosa / *Cowania mexicana* C.T.	Mountains of northern Arizona	Warm dry	Climax	Usually pure stands	*C. mexicana* *B. gracilis* *M. montana*	Hanks et al. 1 3
Pinus ponderosa / *Juniperus communis* H.T.	Bighorn Mountains, north-central Wyoming, Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Warm dry to well-drained	Climax	Usually pure stands	*J. communis* *Hesperochloa kingii* *Astragalus miser* *Poa pratensis* *Clematis tenuiloba* *B. repens* *Spirea betulifolia*	Hoffman 198 Hoffman and ex ander 1976
Pinus ponderosa-*Juniperus scopulorum* H.T.	Black Hills and Bearlodge Mountains South Dakota and eastern Wyoming	Warm dry to well-drained	Climax to co-climax with *J. scopulorum*	*J. scopulorum*	*Stipa comata* *Rhus aromatica* *A. frigida*	Hoffman 198

ble A1.—(continued)

bitat type, mmunity type, or ant community	Location	Site	Successional status of *P. ponderosa*	Principal tree associates	Principal understory species	Authority
nus ponderosa / Physocarpus malvaceus H.T.	Mountains of northern and central Idaho and eastern Washington	Warm dry	Climax	Usually pure stands	*P. malvaceus* *Holodiscus discolor* *Ceanothus sanguineus* *Galium boreale* *Erythronium grandiflorum*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Steele et al. 1981
nus ponderosa / Physocarpus monogynus H.T.	Bighorn Mountains north-central Wyoming; Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Warm dry	Climax	Usually pure stands	*P. monogynus* *S. betulifolia* *Symphoricarpos albus* *B. repens* *P. pratensis* *Cystopteris fragilis*	Hoffman 1984 Hoffman and Alexander 1976
nus ponderosa / Prunus virginiana H.T.	Mountains of southeastern Montana	Warm dry	Climax	Usually pure stands	*P. virginiana* *Amelanchier alnifolia* *S. albus* *B. repens* *Shepherdia canadensis*	Pfister et al. 1977
nus ponderosa / Purshia tridentata H.T.	Mountains of northern and central Idaho, Montana, eastern Washington, southern Utah, and Front Range of north-central Colorado	Warm dry	Climax	*J. scopulorum*	*P. tridentata* *A. tridentata* *Festuca idahoensis* *Agropyron spicatum* *P. virginiana* *C. rossii* *Aristida longiseta* *Balsamorhiza sagittata*	Daubenmire and Daubenmire 1968 Hess 1981 Pfister et al. 1977 Steele et al. 1981 Youngblood 1984
us ponderosa / uercus gambelii H.T. *ponderosa- inus edulis / . gambelii* H.T.]	Mountains of southern Utah, central and southwestern Colorado, New Mexico, and eastern Arizona	Warm dry	Climax	*P. edulis* *P. menziesii* *Juniperus* spp.	*Q. gambelii* *Carex geyeri* *S. oreophilus* *J. communis* *B. repens* *Rosa woodsii* *Koeleria cristata* *Poa fendleriana* *Muhlenbergia* spp. *Schizachyrium scoparium*	Alexander et al. 1984a, 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Hess and Wasser 1982
us ponderosa / uercus grisea H.T.	Mountains of northern New Mexico	Warm dry	Climax	*P. edulis* *Juniperus* spp.	*Q. grisea* *Muhlenbergia* spp.	Fitzhugh et al. 1984
us ponderosa- uercus macrocarpa .T.	Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Warm dry	Climax	*Q. macrocarpa*	*A. alnifolia* *B. repens* *Ostrya virginiana* *Elymus virginicus*	Hoffman 1984
s ponderosa / uercus undulata H.T.	Mountains of eastern Arizona and New Mexico	Warm dry	Climax	*P. edulis* *Juniperus* spp.	*Q. undulata* *Muhlenbergia* spp. *B. gracilis* *Andropogon gerardii*	Alexander et al. 1984a DeVelice et al. 1984
s ponderosa / iraea betulifolia H.T.	Bighorn Mountains, north-central Wyoming	Warm dry	Climax	Usually pure stands	*S. betulifolia* *S. albus* *F. idahoensis* *H. kingii* *C. tenuiloba* *G. boreale*	Hoffman and Alexander 1976

Table A1.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. ponderosa*	Principal tree associates	Principal understory species	Authority
Pinus ponderosa / Symphoricarpos albus H.T.	Mountains of eastern Washington, northern and central Idaho, and central and southeastern Montana; Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Warm dry	Climax	*Populus tremuloides* (SD,WY only and not in all stands)	*S. albus* *S. betulifolia* *B. repens* *Rosa* spp. *J. communis* *S. canadensis* *B. sagittata* *P. virginiana* *Oryzopsis asperifolia* *Carex foenea*	Cooper et al. 19 Daubenmire and Daubenmire 1[illegible]8 Hoffman 1984 Pfister et al. 197 Steele et al. 198
Pinus ponderosa / Symphoricarpos oreophilus H.T.	Mountains of central Idaho and southern Utah	Warm dry	Climax	Usually pure stands (ID) *J. scopulorum* (UT) *P. tremuloides* (UT)	*S. oreophilus* *P. virginiana* *P. tridentata* *A. alnifolia* *A. spicatum* *B. repens*	Steele et al. 198 Youngblood 198
Pinus ponderosa / Agropyron spicatum H.T.	Mountains of eastern Washington, Idaho, and southeastern and west-central Montana, Bighorn Mountains, north-central Wyoming	Hot very dry	Climax	Usually pure stands. May contain *J. scopulorum*	*A. spicatum* *B. sagittata* *Artemisia* spp. *A. longiseta* *Poa* spp. *Bromus tectorum* *Melica bulbosa* *Lomatium dissectum*	Cooper et al. 19 Daubenmire an Daubenmire 1[illegible]8 Hoffman and Al[illegible]ander 1976 Pfister et al. 19 Steele et al. 19
Pinus ponderosa / Andropogon spp. H.T.	Mountains of southeastern Montana	Warm dry	Climax	*J. scopulorum*	*A. gerardii* *A. scoparius*	Pfister et al. 19
Pinus ponderosa / Bouteloua gracilis H.T.	Mountains of Arizona and New Mexico	Warm very dry	Climax	*P. edulis* *Juniperus* spp.	*B. gracilis* *Q. gambelii* *Andropogon hallii* *A. tridentata* *Vitis* spp. *M. montana* *K. cristata*	Alexander et al 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Hanks et al. 19
Pinus ponderosa / Festuca arizonica H.T.	Mountains of Arizona, New Mexico, western and southern Colorado	Warm dry	Climax	Usually pure stands. May contain *P. edulis* *Juniperus* spp.	*F. arizonica* *Q. gambelii* *M. montana* *B. gracilis* *Ceanothus fendleri* *P. fendleriana* *Ribes* spp.	Alexander et a 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Hanks et al. 1[illegible] Komarkova 19
Pinus ponderosa / Festuca idahoensis H.T.	Mountains of eastern Washington, Idaho, central Montana, and northern Utah; Bighorn Mountains, north-central Wyoming	Warm dry	Climax	*Pinus contorta* (UT) *P. tremuloides* (UT) *J. scopulorum* (UT)	*F. idahoensis* *A. spicatum* *B. sagittata* *S. albus* *Calamagrostis rubescens* *Achillea millefolium*	Cooper et al. [illegible] Daubenmire a Daubenmire [illegible] Hoffman and [illegible]ander 1976 Mauk and Her[illegible]son 1980 Pfister et al. 1[illegible]7 Steele et al. 1[illegible]1
Pinus ponderosa / Hesperochloa kingii H.T.	Mountains of southern Wyoming and north-central Colorado	Warm dry	Climax	*P. menziesii* *J. scopulorum*	*H. kingii* *A. frigida* *Ribes cereum* *Geranium richardsonii* *Sedum stenopetalum* *Allium geyeri*	Hess 1981

able A1.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. ponderosa*	Principal tree associates	Principal understory species	Authority
nus ponderosa / Muhlenbergia montana H.T.	Mountains of central and southern Utah, Front Range north-central Colorado, mountains of New Mexico and eastern Arizona	Warm very dry	Climax	*P. menziesii* *P. edulis* *Juniperus* spp.	*M. montana* *Agropyron griffithsii* *Quercus* spp. *Muhlenbergia filiculmis* *Achillea lanulosa* *B. gracilis* *C. rossii*	Alexander et al. 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Hess 1981 Youngblood 1984
nus ponderosa / Muhlenbergia virescens H.T. *. ponderosa / M. Virescens-Festuca arizonica* H.T.] *. ponderosa-M. virescens-F. arizonica-Bouteloua gracilis* C.T.]	Mountains of northern and eastern Arizona, and New Mexico	Warm dry	Climax	*Pinus strobiformis* *P. edulis* *Juniperus deppeana*	*M. virescens* *Q. gambelii* *Carex* spp. *Senecio wootonii* *Pseudocymopterus montanus* *Poa* spp. *C. fendleri* *M. montana* *F. arizonica*	Alexander et al. 1984c Fitzhugh et al. 1984 Hanks et al. 1983
nus ponderosa / Oryzopsis hymenoides H.T.	Mountains of northern New Mexico	Warm dry	Climax	*Juniperus monosperma*	*O. hymenoides* *Muhlenbergia* spp.	DeVelice et al. 1984
nus ponderosa / Poa fendleriana C.T.	Mountains of northern Arizona	Warm dry	Climax	Usually pure stands	*P. fendleriana* *M. montana* *Q. gambelii*	Hanks et al. 1983
nus ponderosa / Poa longiligula C.T.	Mountains of northern Arizona	Warm dry	Climax	Usually pure stands	*P. longiligula* *B. repens* *Senecio multilobatus* *Q. gambelii*	Hanks et al. 1983
nus ponderosa / Stipa comata H.T.	Mountains of northern Idaho and eastern Washington	Warm very dry	Climax	Usually pure stands	*S. comata* *A. longiseta*	Daubenmire and Daubenmire 1968
nus ponderosa / Stipa occidentalis H.T.	Mountains of central Idaho	Warm very dry	Climax	Usually pure stands	*S. occidentalis* *Stipa thurberiana* *P. tridentata*	Steele et al. 1981
nus ponderosa / Carex geyeri H.T.	Mountains of northern Utah, southern Wyoming, and western Colorado	Warm dry	Climax	*P. contorta* *P. tremuloides*	*C. geyeri* *B. repens* *Pachistima myrsinites* *Arnica cordifolia* *Poa nervosa*	Komarkova 1984 Mauk and Henderson 1984 Wirsing and Alexander 1975
nus ponderosa / arex heliophylla H.T.	Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Warm dry	Climax	Usually pure stands	*C. heliophylla*	Hoffman 1984
us ponderosa / arex rossii H.T.	Front Range, north-central Colorado	Warm dry	Climax	Usually pure stands	*C. rossii* *J. communis* *K. cristata* *M. montana* *Mertensia lanceolata*	Hess 1981
us ponderosa / cree H.T. [*onderosa /* ockland H.T.] [*onderosa /Ribes inerme* .T.]	Mountains of eastern Arizona, New Mexico, and southern Colorado	Warm dry	Climax	*P. menziesii* *P. strobiformis*	*Quercus* spp. *Muhlenbergia* spp. *F. arizonica* *R. inerme*	Alexander et al. 1984c DeVelice et al. 1984 Fitzhugh et al. 1984

Table A1.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. ponderosa*	Principal tree associates	Principal understory species	Authority
Pinus ponderosa / Cinder Soils H.T.	Mountains of north-central and northwestern New Mexico	Warm dry	Climax	*P. edulis*	*R. cereum* *M. montana* *Lupinus* spp. *Q. gambelii*	Alexander et al. 1984c
Pinus ponderosa / Riparian H.T. [*P. ponderosa* /*Poa pratensis* H.T.]	Zuni Mountains, New Mexico	Cool moist	Climax	Usually pure stands	*Q. gambelii* *G. boreale* *Iris missouriensis* *P. pratensis* *Juncus* spp.	Alexander et al. 1984c DeVelice 46 al. 1984
			***Pinus flexilis* series**			
Pinus flexilis / *Juniperus communis* H.T.	Front Range, north-central Colorado	Warm dry	Seral to *P. flexilis*	*P. flexilis* *P. contorta* *P. menziesii* *P. tremuloides*	*J. communis* *A. uva-ursi* *Calamagrostis purpurascens* *C. rossii* *Arenaria fendleri* *Erigeron compositus*	Hess 1981
Pinus flexilis / *Agropyron spicatum* H.T.	Mountains of Montana east of Continental Divide	Warm very dry	Minor climax to *P. flexilis*	*P. flexilis* *J. scopulorum* (co-climax)	*A. spicatum* *H. kingii* *K. cristata* *B. gracilis*	Pfister et al. 19
			***Pseudotsuga menziesii* series**			
Pseudotsuga menziesii / *Acer glabrum* H.T.	Mountains of central Idaho	Cool moist	Seral to *P. menziesii*	*P. menziesii* *P. tremuloides*	*A. glabrum* *A. alnifolia* *P. virginiana* *Penstemon wilcoxii* *Arenaria macrophylla*	Steele et al. 19
Pseudotsuga menziesii / *Arctostaphylos patula* H.T.	Mountains of central and southern Utah	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. flexilis* *J. scopulorum*	*A. patula* *B. repens* *Ceanothus martinii* *S. oreophilus*	Youngblood 19
Pseudotsuga menziesii / *Arctostaphylos uva-ursi* H.T.	Mountains of central Montana; mountains of southwestern New Mexico	Warm very dry	Seral to *P. menziesii*	*P. menziesii* *P. flexilis* *P. tremuloides* (NM) *P. strobiformis* (NM)	*A. uva-ursi* *A. spicatum* *Festuca* spp. *B. sagittata* *Lithospermum ruderale*	Pfister et al. 19 Fitzhugh et al. 1984
Pseudotsuga menziesii / *Berberis repens* H.T.	Mountains of central and southern Idaho, and Utah, Bighorn Mountains, north-central Wyoming	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. flexilis* *P. contorta* *P. tremuloides* *Abies grandis* (Not WY) *J. scopulorum*	*B. repens* *J. communis* *P. myrsinites* *C. geyeri* *S. oreophilus* *A. cordifolia*	Hoffman and A ander 1976 Mauk and Hen son 1984 Steele et al. 19 Youngblood 19
Pseudotsuga menziesii / *Cercocarpus ledifolius* H.T.	Mountains of central Idaho and central and southern Utah	Warm dry	Co-climax with (ID) or seral to (UT) *P. menziesii*	*P. menziesii* *P. flexilis* *P. tremuloides* *J. scopulorum*	*C. ledifolius* *S. oreophilus* *A. spicatum* *B. repens*	Steele et al. 19 Youngblood 19
Pseudotsuga menziesii / *Jamesia americana* H.T.	Front Range, north-central Colorado	Warm dry	Seral to *P. menziesii*	*P. menziesii* *J. scopulorum*	*J. americana* *J. communis* *A. glabrum* *Fragaria ovalis* *Potentilla fissa*	Hess 1981

able A1.—(continued)

abitat type, ommunity type, or ant community	Location	Site	Successional status of *P. ponderosa*	Principal tree associates	Principal understory species	Authority
eudotsuga menziesii / Linnaea borealis H.T.	Mountains of central and northwestern Montana, and central Idaho	Warm moist to well-drained	Seral to *P. menziesii*	*P. menziesii* *Larix occidentalis* *P. contorta*	*L. borealis* *C. rubescens* *S. albus* *Vaccinium globulare* *A. cordifolia*	Pfister et al. 1977 Steele et al. 1981
eudotsuga menziesii / Physocarpus malvaceus H.T.	Mountains of eastern Washington, Idaho, and Montana	Cool moist to well-drained	Seral to *P. menziesii*	*P. menziesii* *L. occidentalis* *P. contorta*	*P. malvaceus* *S. albus* *H. discolor* *A. cordifolia* *B. repens* *C. geyeri* *C. rubescens*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981
eudotsuga menziesii / Physocarpus monogynus H.T.	Bighorn Mountains north-central Wyoming. Front Range north-central Colorado	Warm well-drained	Seral to *P. menziesii*	*P. menziesii* *P. contorta* *J. scopulorum* *P. flexilis*	*P. monogynus* *B. repens* *S. betulifolia* *H. kingii* *G. fremontii* *P. pratensis*	Hess 1981 Hoffman and Alexander 1976
eudotsuga menziesii / Quercus gambelii H.T.	Mountains of southern Utah, northern New Mexico, and southern Colorado	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. strobiformis* *Abies concolor* *J. scopulorum*	*Q. gambelii* *F. arizonica* *Muhlenbergia* spp. *S. oreophilus* *B. repens* *P. myrsinites*	Alexander et al. 1984a, 1984b, 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Youngblood 1984
eudotsuga menziesii / Quercus hypoleucoides H.T.	Mountains of southern Arizona and southwestern New Mexico	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. strobiformis* *A. concolor*	*Q. hypoleucoides* *Quercus rugosa* *Muhlenbergia longiligula*	Moir and Ludwig 1979
udotsuga menziesii / piraea betulifolia H.T.	Mountains of central Montana and central Idaho	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. contorta* *P. flexilis*	*S. betulifolia* *A. alnifolia* *B. repens* *A. cordifolia* *Fragaria virginiana* *C. rubescens*	Pfister et al. 1977 Steele et al. 1981
udotsuga menziesii / ymphoricarpos albus .T.	Mountains of eastern Washington, northern and central Idaho, and Montana	Warm dry	Seral to *P. menziesii*	*P. menziesii* *L. occidentalis* *P. contorta*	*S. albus* *S. betulifolia* *Rosa* spp. *C. geyeri* *C. rubescens* *P. virginiana*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981
udotsuga menziesii / ymphoricarpos eophilus H.T.	Mountains of central Idaho, and northern and southern Utah	Warm dry	Seral or minor climax to *P. menziesii*	*P. menziesii* *P. flexilis* *P. tremuloides* *A. grandis* *J. scopulorum* *P. contorta*	*S. oreophilus* *Ribes* spp. *P. virginiana* *A. tridentata* *H. kingii* *Stellaria jamesiana* *B. repens*	Mauk and Henderson 1984 Steele et al. 1981 Youngblood 1984
udotsuga menziesii / accinium caespitosum T.	Mountains of northern and central Idaho, west-central and northwestern Montana	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. contorta* *L. occidentalis*	*V. caespitosum* *C. rubescens* *C. geyeri* *L. borealis* *A. uva-ursi*	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981
idotsuga menziesii / accinium globulare H.T.	Mountains of northern and central Idaho, and north-central Montana	Cool dry	Seral to *P. menziesii*	*P. menziesii* *P. contorta* *L. occidentalis*	*V. globulare* *A. uva-ursi* *Xerophyllum tenax* *C. geyeri*	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981

Table A1.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. ponderosa*	Principal tree associates	Principal understory species	Authority
Pseudotsuga menziesii / *Agropyron spicatum* H.T.	Mountains of central Montana, northern and central Idaho	Warm dry	Co-climax with *P. menziesii*	*P. menziesii* *P. flexilis* *J. scopulorum*	*A. spicatum* *F. idahoensis* *B. sagittata* *M. bulbosa*	Cooper et al. 19 Pfister et al. 19 Steele et al. 198
Pseudotsuga menziesii / *Bromus ciliatus* H.T.	Mountains of north-central and northwestern New Mexico	Warm moist	Minor climax to *P. menziesii*	*P. menziesii* *P. strobiformis* *P. tremuloides*	*B. ciliatus* *A. glabrum* *Carex* spp.	Alexander et al. 1984c
Pseudotsuga menziesii / *Calamagrostis rubescens* H.T.	Mountains of eastern Washington, and Idaho, and Montana	Warm to cool dry to well-drained	Seral to *P. menziesii*	*P. menziesii* *P. contorta* *L. occidentalis* *P. tremuloides*	*C. rubescens* *C. geyeri* *A. uva-ursi* *A. cordifolia* *A. spicatum* *P. myrsinites*	Cooper et al. 19 Daubenmire an Daubenmire 1 Pfister et al. 19 Steele et al. 19
Pseudotsuga menziesii / *Festuca arizonica* H.T.	Mountains of New Mexico, Arizona, and southern Colorado	Warm dry	Seral to *P. menziesii*	*P. menziesii* *Pinus aristata* *P. strobiformis* *P. tremuloides* *P. flexilis*	*F. arizonica* *K. cristata* *M. montana* *P. fendleriana*	Alexander et al. 1984b, 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwi 1979
Pseudotsuga menziesii / *Festuca idahoensis* H.T.	Mountains of northern and central Idaho	Warm dry	Co-climax with *P. menziesii*	*P. menziesii*	*F. idahoensis* *P. virginiana* *Rosa* spp. *A. alnifolia* *A. spicatum* *C. rubescens*	Cooper et al. 19 Steele et al. 19
Pseudotsuga menziesii / *Festuca scabrella* H.T.	Mountains of central and northwestern Montana	Warm dry	Co-climax with *P. menziesii*	*P. menziesii* *P. flexilis*	*F. scabrella* *F. idahoensis* *A. spicatum* *K. cristata* *B. sagittata*	Pfister et al. 19
Pseudotsuga menziesii / *Muhlenbergia montana* H.T.	Mountains of New Mexico and eastern Arizona	Warm dry	Co-climax with *P. menziesii*	*P. menziesii* *P. strobiformis* *Juniperus* spp.	*M. montana* *Q. gambelii* *P. fendleriana* *B. repens*	Alexander et al 1984c Fitzhugh et al. 1984
Pseudotsuga menziesii / *Muhlenbergia virescens* H.T. [*P. menziesii*-*Pinus strobiformis* / *M. virescens* H.T.]	Mountains of New Mexico and northern Arizona	Warm dry	Co-climax with *P. menziesii* *P. strobiformis*	*P. menziesii* *Picea pungens* *P. strobiformis* *P. tremuloides* *A. concolor*	*M. virescens* *Q. gambelii* *C. rossii* *P. fendleriana* *B. ciliatus*	Alexander et al 1984b Fitzhugh et al. 1984 Moir and Ludw 1979
Pseudotsuga menziesii / *Carex geyeri* H.T.	Mountains of Montana east of Continental Divide and central Idaho	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. contorta* *L. occidentalis*	*C. geyeri* *A. uva-ursi* *A. spicatum* *A. cordifolia* *S. oreophilus* *P. virginiana*	Pfister et al. 19 Steele et al. 19
Pseudotsuga menziesii / *Carex rossii* H.T.	Front Range, north-central Colorado	Warm dry	Seral to *P. menziesii*	*P. menziesii* *J. scopulorum*	*C. rossii* *J. communis* *A. lanulosa* *Campanula rotundifolia* *C. fragilis*	Hess 1981

ble A1.—(continued)

abitat type, mmunity type, or ant community	Location	Site	Successional status of *P. ponderosa*	Principal tree associates	Principal understory species	Authority
eudotsuga menziesii / *Osmorhiza chilensis* H.T.	Mountains of central Idaho	Warm well-drained	Seral to *P. menziesii*	*P. menziesii*	*O. chilensis* *C. geyeri* *C. rubescens*	Steele et al. 1981
eudotsuga menziesii / Sparse H.T.	Mountains of northern Arizona	Warm dry	Seral to *P. menziesii*	*P. menziesii* *A. concolor* *P. strobiformis*	*B. repens* *Bromus richardsonii* *P. fendleriana*	Alexander et al. 1984b
***Pinus strobiformis* series**						
us strobiformis / *Festuca arizonica* H.T.	Mountains of northern Arizona	Warm dry	Seral to *P. menziesii* *P. strobiformis*	*P. menziesii* *P. strobiformis*	*F. arizonica* *Muhlenbergia* spp.	Moir and Ludwig 1979
***Abies concolor* series**						
ies concolor / *Acer glabrum* H.T.	Mountains of north-central and northwestern New Mexico	Warm moist	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. strobiformis* *P. tremuloides*	*A. glabrum* *B. repens* *B. richardsonii* *Q. gambelii* *Clematis ligusticifolia*	Alexander et al. 1984c Fitzhugh et al. 1984
ies concolor / *cer grandidentatum* H.T.	Mountains of northern Arizona and New Mexico	Cool moist to warm well-drained	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. tremuloides* *P. strobiformis*	*A. grandidentatum* *Q. gambelii* *C. foenea*	Fitzhugh et al. 1984 Moir and Ludwig 1979
es concolor / *rctostaphylos patula* H.T.	Mountains of southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. pungens* *P. flexilis* *J. scopulorum*	*A. patula* *J. communis* *S. oreophilus* *R. woodsii*	Youngblood 1984
es concolor / *rctostaphylos uva-ursi* .T.	Mountains of northern New Mexico and southern Colorado	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. tremuloides* *P. flexilis*	*A. uva-ursi* *P. myrsinites*	DeVelice et al. 1984
es concolor / *erberis repens* H.T.	Mountains of central and southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. pungens* *P. tremuloides* *P. flexilis*	*B. repens* *S. oreophilus* *P. myrsinites* *J. communis* *R. woodsii*	Youngblood 1984
es concolor / *ercocarpus ledifolius* .T.	Mountains of central and southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. flexilis* *J. scopulorum*	*C. ledifolius* *Q. gambelii* *A. alnifolia* *B. repens* *S. oreophilus*	Youngblood 1984
es concolor- *uercus gambelii* H.T. *concolor-* *seudotsuga menziesii* / *. gambelii* H.T.]	Mountains of Utah, New Mexico, Arizona, and southern Colorado	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. tremuloides* *P. strobiformis* *J. scopulorum*	*Q. gambelii* *M. virescens* *F. arizonica* *S. oreophilus* *A. alnifolia* *B. repens* *C. rossii*	Alexander et al. 1984a, 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979 Youngblood 1984

Table A1.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. ponderosa***	**Principal tree associates**	**Principal understory species**	**Authority**
Abies concolor / Robinia neomexicana H.T. [*A. concolor-Pseudotsuga menziesii / R. neomexicana* H.T.]	Mountains of Arizona and southwestern New Mexico	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. tremuloides* *P. strobiformis* *Picea engelmannii*	*R. neomexicana* *S. oreophilus* *Q. gambelii*	Fitzhugh et al. 1984 Moir and Ludw 1979
Abies concolor / Symphoricarpos oreophilus H.T.	Mountains of central and southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. tremuloides* *J. scopulorum*	*S. oreophilus* *R. woodsii* *A. alnifolia* *C. rossii* *P. fendleriana*	Youngblood 19
Abies concolor / Elymus triticoides H.T. [*A. concolor-Pseudotsuga menziesii / E. triticoides* H.T.]	Capitan Mountains, New Mexico	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. tremuloides* *P. strobiformis*	*E. triticoides* *B. richardsonii*	Moir and Ludw 1979
Abies concolor / Festuca arizonica H.T.	Mountains of northern New Mexico and eastern Arizona	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. tremuloides* *P. strobiformis*	*F. arizonica* *Q. gambelii* *Muhlenbergia* spp. *Poa* spp.	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludw 1979
Abies concolor / Muhlenbergia virescens H.T.	Mountains of eastern Arizona and southwestern New Mexico	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. strobiformis*	*M. virescens* *Lupinus* spp. *P. fendleriana* *Senecio* spp.	Fitzhugh et al. 1984
Abies concolor / Poa fendleriana H.T. [*A. concolor-Pseudotsuga menziesii / P. fendleriana* H.T.]	White Mountains, Arizona	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. strobiformis* *P. tremuloides*	*P. fendleriana* *Fragaria vesca* *S. wootonii* *G. richardsonii* *Erigeron* spp.	Moir and Ludw 1979
Abies concolor / Carex foenea H.T.	Pinaleno Mountains, Arizona	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. strobiformis*	*C. foenea*	Moir and Ludw 1979
Abies concolor / Erigeron eximius H.T. [*A. concolor-Pseudotsuga menziesii / E. superbus* H.T.]	Mountains of northern New Mexico and Arizona	Cool moist	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. tremuloides* *P. strobiformis* *P. pungens* *P. engelmannii*	*E. superbus* (E. eximius) *C. foenea* *Lathyrus arizonicus* *P. virginiana*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludw 1979
Abies concolor / Lathyrus arizonicus H.T. [*A. concolor-Pseudotsuga menziesii / L. arizonicus* H.T.]	San Francisco Peaks, Arizona	Cool dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. tremuloides*	*L. arizonicus* *G. richardsonii*	Moir and Ludw 1979
Abies concolor / Sparse H.T. [*A. concolor-Pseudotsuga menziesii* H.T.]	Mountains of New Mexico and southern Colorado	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. pungens* *P. strobiformis* *P. tremuloides*	*S. oreophilus* *R. neomexicana* *Q. gambelii* *B. repens*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludw 1979
***Abies grandis* series**						
Abies grandis / Acer glabrum H.T.	Mountains of central Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *Abies lasiocarpa* (minor climax) *P. menziesii*	*A. glabrum* *S. albus* *P. malvaceus* *S. betulifolia* *C. rubescens*	Steele et al. 1

ble A1.—(continued)

bitat type, mmunity type, or ant community	Location	Site	Successional status of *P. ponderosa*	Principal tree associates	Principal understory species	Authority
ies grandis / Linnaea borealis H.T.	Mountains of central and northern Idaho, and southern Montana	Warm moist to well-drained	Seral to *A. grandis*	*A. grandis* *P. menziesii* *P. engelmannii* *P. contorta* *L. occidentalis* *A. lasiocarpa*	*L. borealis* *X. tenax* *C. rubescens* *A. alnifolia* *A. cordifolia* *Lupinus* spp.	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981
ies grandis / Pachistima myrsinites H.T.	Mountains of northern Idaho and eastern Washington	Warm dry to well-drained	Seral to *A. grandis*	*A. grandis* *P. menziesii* *L. occidentalis* *P. contorta*	*P. myrsinites* *Bromus vulgaris* *Galium triflorum* *Smilacina stellata* *Thalictrum occidentale*	Daubenmire and Daubenmire 1968
ies grandis / Physocarpus malvaceus H.T.	Mountains of northern Idaho	Warm dry	Seral to *A. grandis*	*A. grandis* *P. menziesii* *P. contorta* *L. occidentalis*	*P. malvaceus* *A. glabrum* *H. discolor* *Smilacina racemosa*	Cooper et al. 1983
ies grandis / Spiraea betulifolia H.T.	Mountains of central Idaho	Warm dry	Seral to *A. grandis*	*A. grandis* *P. menziesii* *P. tremuloides*	*S. betulifolia* *S. albus* *A. cordifolia* *C. rubescens*	Steele et al. 1981
ies grandis / Vaccinium caespitosum H.T.	Mountains of central Idaho	Cool moist to well-drained	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* (minor climax) *P. engelmannii* *P. menziesii* *P. contorta* *L. occidentalis*	*V. caespitosum* *F. virginiana* *C. rubescens*	Steele et al. 1981
ies grandis / Vaccinium globulare H.T.	Mountains of central Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* (minor climax) *P. menziesii* *P. contorta* *P. engelmannii* *L. occidentalis*	*V. globulare* *Lonicera utahensis*	Steele et al. 1981
es grandis / Xerophyllum tenax H.T.	Mountains of northern Idaho and northwestern Montana	Warm dry	Seral to *A. grandis*	*A. grandis* *P. menziesii* *P. contorta* *L. occidentalis* *P. engelmannii* *A. lasiocarpa*	*X. tenax* *V. globulare* *C. rubescens* *Arnica latifolia* *P. myrsinites*	Cooper et al. 1984 Pfister et al. 1977
es grandis / Calamagrostis rubescens H.T.	Mountains of central Idaho	Cool dry	Seral to *A. grandis*	*A. grandis* *P. contorta* *P. menziesii*	*C. rubescens* *C. geyeri* *S. betulifolia* *A. cordifolia*	Steele et al. 1981
es grandis / Clintonia uniflora H.T.	Mountains of northern Montana, northern and central Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* (minor climax) *P. menziesii* *P. engelmannii* *Pinus monticola* *L. occidentalis* *P. contorta*	*C. uniflora* *A. glabrum* *V. globulare* *L. borealis* *G. triflorum* *B. vulgaris* *P. malvaceus* *X. tenax*	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981
es grandis / optis occidentalis H.T.	Mountains of northern Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *P. menziesii* *P. contorta* *L. occidentalis* *P. engelmannii* *A. lasiocarpa*	*C. occidentalis* *P. malvaceus* *V. globulare* *X. tenax* *S. albus* *H. discolor*	Cooper et al. 1983

Table A1.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. ponderosa*	Principal tree associates	Principal understory species	Authority
			***Picea pungens* series**			
Picea pungens *Arctostaphylos uva-ursi* H.T. [*P. pungens*-*Pseudotsuga menziesii* / *A. uva-ursi* H.T.]	Mountains of southern Colorado and northern New Mexico	Warm dry	Seral to *P. pungens* *P. menziesii* *A. concolor*	*P. pungens* *P. menziesii* *A. concolor* *P. tremuloides* *P. flexilis*	*A. uva-ursi* *J. communis* *F. arizonica* *F. ovalis*	DeVelice et al. 1984 Moir and Ludw 1979
Picea pungens / *Berberis repens* H.T.	Mountains of central and southern Utah	Cool dry	Seral to *P. pungens*	*P. pungens* *P. menziesii* *P. tremuloides* *P. flexilis* *J. scopulorum*	*B. repens* *P. myrsinites* *J. communis* *S. oreophilus* *C. rossii*	Youngblood 19
Picea pungens / *Juniperus communis* H.T.	Mountains of central Utah	Warm dry	Seral to *P. pungens*	*P. pungens* *P. menziesii* *P. tremuloides* *P. flexilis* *J. scopulorum*	*J. communis* *A. uva-ursi* *B. repens* *P. myrsinites* *S. oreophilus*	Youngblood 19
Picea pungens / *Agropyron spicatum* H.T.	Uinta Mountains, Utah	Warm dry	Seral to *P. pungens*	*P. pungens* *P. menziesii* *P. tremuloides* *P. contorta* *P. flexilis* *J. scopulorum*	*A. spicatum* *B. repens* *J. communis* *P. myrsinites*	Mauk and Hen- son 1984
Picea pungens / *Festuca arizonica* H.T.	Jemez Mountains, northern New Mexico, San Juan Mountains, southwestern Colorado	Warm dry	Seral to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *A. concolor* *P. tremuloides*	*F. arizonica* *C. foenea* *Erigeron* spp. *Fragaria* spp.	DeVelice et al. 1984
Picea pungens / *Poa pratensis* H.T.	Mountains of New Mexico	Warm to cool moist	Seral to *P. pungens*	*P. pungens* *P. menziesii* *P. tremuloides* *A. concolor* *P. strobiformis*	*P. pratensis* *E. superbus* (E. eximius) *G. richardsonii* *F. virginiana*	Fitzhugh et al. 1984 Moir and Ludw 1979
Picea pungens / *Carex foenea* H.T.	Mountains of northern Arizonia and New Mexico	Warm to cool moist	Seral to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *A. concolor* *P. tremuloides* *P. strobiformis*	*C. foenea* *F. arizonica* *M. montana* *B. ciliatus* *Fragaria* spp.	DeVelice et al. 1984 Moir and Ludw 1979
Picea pungens / *Erigeron eximius* H.T. [*P. pungens*-*Picea engelmannii* / *E. superbus* H.T.]	White Mountains, Arizona	Cool dry	Seral to *P. pungens* *P. engelmannii* *P. menziesii*	*P. pungens* *P. engelmannii* *P. menziesii* *A. concolor* *A. lasiocarpa* *P. tremuloides* *P. strobiformis*	*E. superbus* (E. eximius) *F. arizonica* *C. foenea* *F. virginiana*	Moir and Ludw 1979
Picea pungens / *Fragaria ovalis* H.T. [*P. pungens*-*Pseudotsuga menziesii* / *Valeriana acutiloba* H.T.]	Mountains of New Mexico and eastern Arizona	Cool moist	Seral to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *A. concolor* *P. strobiformis* *P. tremuloides* *P. engelmannii* *A. lasiocarpa*	*F. ovalis* *V. acutiloba* *C. foenea* *F. arizonica* *E. superbus* (E. eximius)	Alexander et a 1984a Fitzhugh et al. 1984 Moir and Ludw 1979
Picea pungens / *Senecio cardamine* H.T. [*P. pungens*-*Picea engelmannii* / *S. cardamine* H.T.]	Mountains of southwestern New Mexico and southeastern Arizona	Cool moist	Seral to *P. pungens* *P. engelmannii* *A. lasiocarpa*	*P. pungens* *P. engelmannii* *A. lasiocarpa* *A. concolor* *P. menziesii* *P. tremuloides* *P. strobiformis*	*S. cardamine* *P. aquilinum* *Helenium hoopesii* *Viola canadensis*	Moir and Ludw 1979

able A1.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. ponderosa*	Principal tree associates	Principal understory species	Authority
***Picea glauca* series**						
cea glauca / *Linnaea borealis* H.T.	Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Cool well-drained	Seral to *P. glauca*	*P. glauca* *P. tremuloides* *Betula papyrifera*	*L. borealis* *S. canadensis* *Lonicera dioica*	Hoffman 1984
cea glauca / *Vaccinium scoparium* H.T.	Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Cool well-drained	Seral to *P. glauca*	*P. glauca* *P. tremuloides* *B. papyrifera*	*V. scoparium* *C. tenuiloba*	Hoffman 1984
***Picea engelmannii* series**						
cea engelmannii / *Vaccinium caespitosum* H.T.	Mountains of northwestern Montana	Cool well-drained	Seral to *P. engelmannii*	*P. engelmannii* *L. occidentalis* *P. menziesii* *P. contorta*	*V. caespitosum* *L. borealis* *V. scoparium* *C. rubescens* *Ribes montigenum*	Pfister et al. 1977
cea engelmannii / *Clintonia uniflora* H.T.	Mountains of northwestern Montana	Warm moist to dry	Seral to *P. engelmannii*	*P. engelmannii* *P. contorta* *P. menziesii* *L. occidentalis*	*C. uniflora* *V. caespitosum* *Aralia nudicaulis* *Cornus canadensis*	Pfister et al. 1977
cea engelmannii / *Galium triflorum* H.T.	Mountains of south-central Montana	Cool moist	Seral to *P. engelmannii*	*P. engelmannii* *P. contorta* *P. menziesii*	*G. triflorum* *Actaea rubra* *S. stellata* *Streptopus amplexifolius*	Pfister et al. 1977
cea engelmannii / *Senecio cardamine* H.T.	Blue Mountains, Arizona	Cool moist	Seral to *P. engelmannii* *P. menziesii*	*P. engelmannii* *P. menziesii* *P. strobiformis* *P. tremuloides* *A. lasiocarpa* *A. concolor*	*S. cardamine* *F. ovalis* *G. richardsonii* *P. aquilinum* *V. canadensis*	Fitzhugh et al. 1984
cea engelmannii / *Smilacina stellata* H.T.	Mountains of Montana east of Continental Divide	Warm moist	Seral to *P. engelmannii*	*P. engelmannii* *P. contorta* *P. menziesii*	*S. stellata* *S. racemosa* *T. occidentale*	Pfister et al. 1977
***Abies lasiocarpa* series**						
ies lasiocarpa / *innaea borealis* H.T.	Mountains of Montana	Cool moist to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. tremuloides* *P. engelmannii*	*L. borealis* *A. cordifolia* *V. scoparium* *C. rubescens*	Pfister et al. 1977
ies lasiocarpa / *erophyllum tenax* H.T.	Mountains of Montana	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. albicaulis* *P. contorta* *P. menziesii* *P. engelmannii*	*X. tenax* *Vaccinium membranaceum* *V. scoparium* *V. globulare*	Pfister et al. 1977
es lasiocarpa / *lintonia uniflora* H.T.	Mountains of northwestern Montana	Warm moist to cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. menziesii* *L. occidentalis* *P. monticola*	*C. uniflora* *Menziesia ferruginea* *V. caespitosum* *A. nudicaulis*	Pfister et al. 1977

Table A2.—Habitat types, community types, and plant communities in which interior *Pseudotsuga menziesii* is climax, co-climax, minor climax, or seral.

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. menziesii***	**Principal tree associates**	**Principal understory species**	**Authority**
***Pseudotsuga menziesii* series**						
Pseudotsuga menziesii / *Acer glabrum* H.T.	Mountains of central and eastern Idaho, northwestern Wyoming, and northern Utah	Cool moist	Climax	*Abies grandis* *Populus tremuloides* *Pinus ponderosa* *Pinus contorta* *Pinus flexilis* *Juniperus scopulorum*	*A. glabrum* *Amelanchier alnifolia* *Prunus virginiana* *Symphoricarpos oreophilus* *Ribes cereum*	Mauk and Hend son 1984 Steele et al. 198 1983
Pseudotsuga menziesii / *Arctostaphylos patula* H.T.	Mountains of central and southern Utah	Warm dry	Climax	*P. ponderosa* *P. flexilis* *J. scopulorum*	*A. patula* *Berberis repens* *Ceanothus martinii* *S. oreophilus*	Youngblood 198
Pseudotsuga menziesii / *Arctostaphylos uva-ursi* H.T.	Mountains of central Montana; mountains of southwestern New Mexico	Warm very dry	Climax	*P. ponderosa* *P. flexilis* *P. tremuloides* (NM) *Pinus strobiformis* (NM)	*A. uva-ursi* *Agropyron spicatum* *Festuca* spp. *Balsamorhiza sagittata* *Lithospermum ruderale*	Fitzhugh et al. 1984 Pfister et al. 19
Pseudotsuga menziesii / *Berberis repens* H.T.	Mountains of central and southern Idaho, northwestern Wyoming, and northern Utah; Bighorn Mountains, north-central Wyoming	Warm dry	Climax	*P. ponderosa* *P. flexilis* *P. contorta* *P. tremuloides* *A. grandis* (Not WY) *J. scopulorum*	*B. repens* *Juniperus communis* *Pachistima myrsinites* *Carex geyeri* *S. oreophilus* *Arnica cordifolia*	Hoffman and A ander 1976 Mauk and Henc son 1984 Steele et al. 19 1983 Youngblood 19
Pseudotsuga menziesii / *Cercocarpus ledifolius* H.T.	Mountains of eastern and central Idaho, and Utah	Warm dry	Climax or co-climax with *P. ponderosa*	*P. ponderosa* *A. grandis* *P. flexilis* *J. scopulorum* *P. tremuloides*	*C. ledifolius* *S. oreophilus* *A. spicatum* *B. sagittata* *B. repens*	Mauk and Henc son 1984 Steele et al. 19 1983 Youngblood 19
Pseudotsuga menziesii / *Cercocarpus montanus* H.T.	Mountains of central and southern Utah	Warm dry	Climax	*Juniperus* spp. *Pinus edulis*	*C. montanus* *S. oreophilus* *B. repens* *Shepherdia rotundifolia*	Youngblood 19
Pseudotsuga menziesii / *Jamesia americana* H.T.	Front Range, north-central Colorado; mountains of western Colorado	Warm dry	Climax	*P. ponderosa* *J. scopulorum*	*J. americana* *J. communis* *A. glabrum* *Fragaria ovalis* *Potentilla fissa*	Hess 1981 Komarkova 198
Pseudotsuga menziesii / *Juniperus communis* H.T.	Mountains of central and southwestern Montana, central Idaho, and northwestern Wyoming	Warm dry	Climax	*P. flexilis* *P. contorta* *J. scopulorum*	*J. communis* *S. oreophilus* *Shepherdia canadensis* *A. cordifolia* *Juniperus horizontalis* *Astragalus miser*	Pfister et al. 19 Steele et al. 19 1983

able A2.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
seudotsuga menziesii / Linnaea borealis H.T.	Mountains of central and northwestern Montana, and central Idaho	Warm moist to well-drained	Climax	*P. ponderosa* *Larix occidentalis* *P. contorta*	*L. borealis* *Calamagrostis rubescens* *Symphoricarpos albus* *Vaccinium globulare* *A. cordifolia*	Pfister et al. 1977 Steele et al. 1981
eudotsuga menziesii / Pachistima myrsinites H.T.	Mountains of western and central Colorado	Warm dry	Climax	*P. contorta* *Picea engelmannii* *P. tremuloides*	*P. myrsinites* *S. oreophilus* *A. cordifolia* *B. repens* *Vaccinium myrtillus* *Quercus gambelii*	Hess and Wasser 1982 Hoffman and Alexander 1980, 1983 Komarkova 1984
seudotsuga menziesii / Physocarpus malvaceus H.T.	Mountains of eastern Oregon, and Washington, Idaho, Montana, northwestern Wyoming, and Utah	Cool moist to well-drained	Climax	*P. ponderosa* *L. occidentalis* *P. contorta* *P. tremuloides* *A. grandis* *J. scopulorum* *P. flexilis*	*P. malvaceus* *S. albus* *Holodiscus discolor* *A. cordifolia* *B. repens* *C. geyeri* *P. myrsinites* *A. alnifolia*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983 Youngblood 1984
eudotsuga menziesii / Physocarpus monogynus I.T.	Bighorn Mountains, north-central Wyoming; Front Range, north-central Colorado	Warm well-drained	Climax	*P. contorta* *J. scopulorum* *P. ponderosa* *P. flexilis*	*P. monogynus* *B. repens* *Spiraea betulifolia* *Hesperochloa kingii* *Geranium fremontii* *Poa pratensis*	Hess 1981 Hoffman and Alexander 1976
eudotsuga menziesii / Quercus gambelii H.T.	Mountains of southern Utah, New Mexico, Arizona, and southern Colorado	Warm dry	Climax	*P. ponderosa* *P. strobiformis* *Abies concolor* (AZ) *J. scopulorum*	*Q. gambelii* *Festuca arizonica* *S. oreophilus* *Muhlenbergia virescens* *Holodiscus dumosus* *B. repens* *P. myrsinites* *A. glabrum*	Alexander et al. 1984a, 1984b, 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Youngblood 1984
eudotsuga menziesii / uercus hypoleucoides I.T.	Mountains of southern Arizona and southwestern New Mexico	Warm dry	Climax	*P. ponderosa* *P. strobiformis* *A. concolor*	*Q. hypoleucoides* *Quercus rugosa* *Muhlenbergia longiligula*	Fitzhugh et al. 1984 Moir and Ludwig 1979
eudotsuga menziesii / piraea betulifolia H.T.	Mountains of central Montana, central and eastern Idaho, and northwestern Wyoming	Warm dry	Climax	*P. ponderosa* *P. contorta* *P. flexilis*	*S. betulifolia* *A. alnifolia* *B. repens* *A. cordifolia* *Fragaria virginiana* *C. rubescens*	Pfister et al. 1977 Steele et al. 1981, 1983
udotsuga menziesii / ymphoricarpos albus I.T.	Mountains of eastern Washington, Idaho, Montana, and northwestern Wyoming	Warm dry	Climax	*P. ponderosa* *L. occidentalis* *P. contorta* *P. tremuloides*	*S. albus* *S. betulifolia* *Rosa* spp. *C. geyeri* *C. rubescens* *P. virginiana*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981, 1983

Table A2.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
Pseudotsuga menziesii / Symphoricarpos oreophilus H.T.	Mountains of central Idaho, southwestern Montana, northern and southern Utah, northwestern Wyoming, and western and central Colorado	Warm dry	Climax	*P. ponderosa* *P. flexilis* *P. tremuloides* *A. grandis* *J. scopulorum* *P. contorta*	*S. oreophilus* *Ribes* spp. *P. virginiana* *Artemesia tridentata* *H. kingii* *Stellaria jamesiana* *C. geyeri* *B. repens*	Hess and Wasse 1982 Komarkova 1984 Mauk and Hende son 1984 Pfister et al. 197 Steele et al. 198 1983 Youngblood 198
Pseudotsuga menziesii / Vaccinium caespitosum H.T.	Mountains of northern and central Idaho, west-central and northwestern Montana	Warm moist	Climax	*P. ponderosa* *P. contorta* *L. occidentalis*	*V. caespitosum* *C. rubescens* *C. geyeri* *L. borealis* *A. uva-ursi*	Cooper et al. 198 Pfister et al. 197 Steele et al. 198
Pseudotsuga menziesii / Vaccinium globulare H.T.	Mountains of north-central Montana, northern, central and eastern Idaho	Cool dry	Climax	*P. ponderosa* *P. contorta* *L. occidentalis*	*V. globulare* *A. uva-ursi* *Xerophyllum tenax* *C. geyeri*	Cooper et al. 198 Pfister et al. 197 Steele et al. 198 1983
Pseudotsuga menziesii / Agropyron spicatum H.T.	Mountains of central Montana, northern and central Idaho	Warm dry	Co-climax with *P. ponderosa*	*P. ponderosa* *P. flexilis* *J. scopulorum*	*A. spicatum* *Festuca idahoensis* *B. sagittata* *Melica bulbosa*	Cooper et al. 198 Pfister et al. 197 Steele et al. 198
Pseudotsuga menziesii / Bromus ciliatus H.T.	Mountains of New Mexico	Warm moist	Climax	*P. ponderosa* (minor climax) *P. strobiformis* *P. tremuloides*	*B. ciliatus* *F. arizonica* *Poa fendleriana* *A. glabrum*	Alexander et al. 1984c Fitzhugh et al.19
Pseudotsuga menziesii / Calamagrostis rubescens H.T.	Mountains of eastern Washington, Idaho, Montana, and northwestern Wyoming	Warm to cool dry to well-drained	Climax	*P. ponderosa* *P. contorta* *L. occidentalis* *P. tremuloides* *P. flexilis*	*C. rubescens* *C. geyeri* *A. uva-ursi* *A. cordifolia* *A. spicatum* *P. myrsinites*	Cooper et al. 19 Daubenmire and Daubenmire 1 Pfister et al. 197 Steele et al. 198 1983
Pseudotsuga menziesii / Festuca arizonica H.T.	Mountains of New Mexico, Arizona, and southern Colorado	Warm dry	Climax	*P. ponderosa* *P. strobiformis* *Pinus aristata* *P. tremuloides* *P. flexilis*	*F. arizonica* *Muhlenbergia montana* *Koeleria cristata* *P. fendleriana* *Q. gambelii*	Alexander et al. 1984b, 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwi 1979
Pseudotsuga menziesii / Festuca idahoensis H.T.	Mountains of southwestern Montana, northern and central Idaho	Warm dry	Co-climax with *P. ponderosa*	*P. ponderosa*	*F. idahoensis* *P. virginiana* *Rosa* spp. *A. alnifolia* *A. spicatum* *C. rubescens*	Cooper et al. 19 Pfister et al. 197 Steele et al. 198
Pseudotsuga menziesii / Festuca scabrella H.T.	Mountains of central and northwestern Montana	Warm dry	Co-climax with *P. ponderosa*	*P. ponderosa* *P. flexilis*	*F. scabrella* *F. idahoensis* *A. spicatum* *K. cristata* *B. sagittata*	Pfister et al. 197

Table A2.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
seudotsuga menziesii / Muhlenbergia montana H.T.	Mountains of New Mexico and eastern Arizona	Warm dry	Co-climax with *P. ponderosa*	*P. ponderosa* *P. strobiformis* *Juniperus* spp.	*M. montana* *Q. gambelii* *P. fendleriana* *B. repens*	Alexander et al. 1984c Fitzhugh et al. 1984
seudotsuga menziesii / Muhlenbergia virescens H.T. *. menziesii-Pinus strobiformis / M. virescens* H.T.]	Mountains of New Mexico and northern Arizona	Warm dry	Co-climax with *P. ponderosa* *P. strobiformis*	*P. ponderosa* *P. strobiformis* *Picea pungens* *P. tremuloides* *A. concolor*	*M. virescens* *Q. gambelii* *Carex rossii* *P. fendleriana* *B. ciliatus*	Alexander et al. 1984b Fitzhugh et al. 1984 Moir and Ludwig 1979
seudotsuga menziesii / Carex geyeri H.T.	Mountains of Montana east of Continental Divide and central Idaho; mountains of western and central Colorado	Warm dry	Climax	*P. ponderosa* *P. contorta* *L. occidentalis* *J. scopulorum*	*C. geyeri* *A. uva-ursi* *A. spicatum* *A. cordifolia* *S. oreophilus* *P. virginiana*	Hess 1981 Komarkova 1984 Pfister et al. 1977 Steele et al. 1981
seudotsuga menziesii / Carex rossii H.T.	Front Range of north-central Colorado	Warm dry	Climax	*P. ponderosa* *J. scopulorum*	*C. rossii* *J. communis* *Achillea lanulosa* *Campanula rotundifolia* *Cystopteris fragilis*	Hess 1981
seudotsuga menziesii / Arnica cordifolia H.T.	Mountains of central and southwestern Montana, eastern and central Idaho, and northwestern Wyoming	Cool to warm dry	Climax	*P. flexilis* *P. contorta*	*A. cordifolia* *A. miser* *S. oreophilus* *Poa nervosa* *J. communis*	Pfister et al. 1977 Steele et al. 1981, 1983
seudotsuga menziesii / Holodiscus dumosus H.T. (Scree Forest) *. menziesii / Physocarpus monogynus* H.T.]	Mountains of New Mexico and southern Colorado	Warm dry to well-drained	Climax	*Abies lasiocarpa* *P. engelmannii* *P. tremuloides* *P. strobiformis* *P. pungens* *A. concolor*	*H. dumosus* *Salix* spp. *P. monogynus* *S. oreophilus* *B. ciliatus*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
seudotsuga menziesii / Osmorhiza chilensis H.T.	Mountains of central and southern Idaho, and northern Utah	Warm well-drained	Climax	*P. ponderosa* *P. tremuloides* *P. contorta* *A. grandis* *J. scopulorum*	*O. chilensis* *Smilacina racemosa* *Viola nuttallii* *P. virginiana* *A. cordifolia* *C. rubescens*	Mauk and Henderson 1984 Steele et al. 1981, 1983
seudotsuga menziesii / Sparse H.T.	Mountains of northern Arizona	Warm dry	Climax	*P. ponderosa* *A. concolor* *P. strobiformis*	*B. repens* *Bromus richardsonii* *P. fendleriana*	Alexander et al. 1984b
			***Pinus flexilis* series**			
nus flexilis / Arctostaphylos uva-ursi H.T.	Mountains of northern New Mexico and southern Colorado	Warm dry	Co-climax with *P. flexilis*	*P. flexilis* *P. engelmannii* (minor climax) *P. tremuloides*	*A. uva-ursi* *J. communis*	DeVelice et al. 1984

Table A2.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. menziesii***	**Principal tree associates**	**Principal understory species**	**Authority**
Pinus flexilis / Berberis repens H.T.	Mountains of northern Utah	Warm dry	Minor climax to *P. flexilis*	*P. flexilis* *J. scopulorum*	*B. repens* *P. myrsinites* *S. oreophilus* *A. spicatum* *P. virginiana*	Mauk and Hende son 1984
Pinus flexilis / Cercocarpus ledifolius H.T.	Mountains of eastern Idaho and northern Utah	Warm dry	Co-climax with or minor climax to *P. flexilis*	*P. flexilis* *J. scopulorum*	*C. ledifolius* *B. repens* *S. oreophilus* *B. sagittata* *A. spicatum* *H. kingii*	Mauk and Hende son 1984 Steele et al. 198
Pinus flexilis / Juniperus communis H.T.	Mountains of Montana and northwestern Wyoming; Front Range, north-central Colorado	Warm dry	Minor climax to *P. flexilis*	*P. flexilis* *P. contorta* *P. ponderosa* *P. tremuloides*	*J. communis* *A. uva-ursi* *Calamagrostis purpurascens* *C. rossii* *A. cordifolia* *S. canadensis*	Hess 1981 Pfister et al. 197 Steele et al. 198
Pinus flexilis / Festuca idahoensis H.T.	Mountains of southwestern Montana, central Idaho, and northwestern Wyoming	Warm dry	Co-climax with *P. flexilis*	*P. flexilis* *J. scopulorum*	*F. idahoensis* *F. scabrella* *A. spicatum* *B. sagittata* *H. kingii* *A. tridentata*	Pfister et al. 197 Steele et al. 198 1983
Pinus flexilis / Hesperochloa kingii H.T.	Mountains of northwestern Wyoming	Warm dry	Co-climax with *P. flexilis*	*P. flexilis* *J. scopulorum*	*H. kingii* *A. spicatum* *C. rossii* *A. miser* *B. sagittata*	Steele et al. 198
Pinus flexilis-Pinus longaeva H.T.	Mountains of central and southern Utah	Warm dry	Seral to *P. flexilis* *P. longaeva*	*P. flexilis* *P. longaeva* *P. tremuloides* *J. scopulorum*	*S. oreophilus* *J. communis* *B. repens* *C. rossii* *A. miser*	Youngblood 198
			***Pinus ponderosa* series**			
Pinus ponderosa / Arctostaphylos uva-ursi H.T.	Mountains of northern New Mexico and southern Colorado	Warm dry	Minor climax to *P. ponderosa*	*P. ponderosa*	*A. uva-ursi* *F. arizonica* *M. montana*	DeVelice et al. 1984
Pinus ponderosa / Quercus gambelii H.T.	Mountains of western and central Colorado	Warm dry	Minor climax to *P. ponderosa*	*P. ponderosa* *J. scopulorum*	*Q. gambelii* *C. geyeri* *S. oreophilus* *J. communis* *B. repens* *Rosa woodsii*	Hess and Wass 1982
Pinus ponderosa / Hesperochloa kingii H.T.	Mountains of southern Wyoming and north-central Colorado	Warm dry	Minor climax to *P. ponderosa*	*P. ponderosa* *P. flexilis*	*H. kingii* *Artemisia frigida* *R. cereum* *Geranium richardsonii* *Sedum stenopetalum* *Allium geyeri*	Hess 1981

able A2.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
inus ponderosa / *Muhlenbergia montana* H.T.	Front Range, north-central Colorado; mountains of eastern Arizona and southwestern New Mexico	Warm very dry	Seral to *P. ponderosa*	*P. ponderosa* *J. scopulorum* *P. edulis* *Juniperus deppeana*	*M. montana* *Agropyron griffithsii* *H. kingii* *Muhlenbergia filiculmis* *A. lanulosa* *G. fremontii*	Fitzhugh et al. 1984 Hess 1981
inus ponderosa / Scree H.T. *. ponderosa* / Rockland H.T.]	Mountains of eastern Arizona and southwestern New Mexico	Warm dry	Minor climax to *P. ponderosa*	*P. ponderosa* *P. strobiformis*	*Quercus* spp. *Muhlenbergia* spp. *F. arizonica*	Fitzhugh et al. 1984
			***Pinus strobiformis* series**			
inus strobiformis / *Festuca arizonica* H.T.	Mountains of northern Arizona	Warm dry	Co-climax with *P. strobiformis*	*P. strobiformis* *P. ponderosa*	*F. arizonica* *Muhlenbergia* spp.	Moir and Ludwig 1979
			***Pinus aristata* series**			
inus aristata / *Festuca arizonica* H.T.	Sangre de Cristo Mountains, New Mexico	Warm dry	Co-climax with *P. aristata*	*P. aristata* *P. tremuloides*	*F. arizonica* *K. cristata* *M. montana* *P. fendleriana*	DeVelice et al. 1984
			***Abies concolor* series**			
ies concolor *Acer glabrum* H.T. *. concolor-Pseudotsuga menziesii* / *A. glabrum* H.T.]	Mountains of southern Utah, New Mexico, Arizona, and southern Colorado	Warm moist to well-drained	Co-climax with *A. concolor*	*A. concolor* *P. tremuloides* *P. strobiformis* *P. pungens* *P. engelmannii* *P. ponderosa* (NM) *A. lasiocarpa*	*A. glabrum* *B. repens* *Q. gambelii* *H. dumosus* *P. myrsinites* *P. virginiana* *A. alnifolia*	Alexander et al. 1984a, 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979 Youngblood 1984
ies concolor / *Acer grandidentatum* H.T.	Mountains of Arizona and New Mexico	Cool moist	Seral to *A. concolor*	*A. concolor* *P. ponderosa* (AZ) *P. tremuloides* *P. strobiformis*	*A. grandidentatum* *Q. gambelii* *Carex foenea* *H. dumosus*	Alexander et al. 1984a Fitzhugh et al. 1984 Moir and Ludwig 1979
ies concolor / *Arctostaphylos patula* H.T.	Mountains of southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. pungens* *P. ponderosa* *P. flexilis* *J. scopulorum*	*A. patula* *J. communis* *S. oreophilus* *R. woodsii*	Youngblood 1984
ies concolor / *Arctostaphylos uva-ursi* H.T.	Mountains of northern New Mexico and southern Colorado	Warm dry	Co-climax with *A. concolor*	*A. concolor* *P. ponderosa* *P. tremuloides* *P. flexilis*	*A. uva-ursi* *P. myrsinites*	DeVelice et al. 1984

Table A2.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. menziesii***	**Principal tree associates**	**Principal understory species**	**Authority**
Abies concolor / *Berberis repens* H.T.	Mountains of northern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. contorta* *P. flexilis* *A. grandis* *P. tremuloides* *P. ponderosa* *P. pungens*	*B. repens* *S. oreophilus* *Osmorhiza* spp. *Lathyrus leucanthus* *J. communis* *R. woodsii* *P. myrsinites*	Mauk and Hende son 1984 Youngblood 1984
Abies concolor / *Cercocarpus ledifolius* H.T.	Mountains of central and southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. ponderosa* *P. flexilis* *J. scopulorum*	*C. ledifolius* *Q. gambelii* *A. alnifolia* *B. repens* *S. oreophilus*	Youngblood 1984
Abies concolor / *Juglans major* H.T.	Mountains of southern New Mexico	Warm moist	Seral to *A. concolor*	*A. concolor* *Populus angustifolia* *Fraxinus pennsylvanica* *P. tremuloides*	*J. major* *Q. gambelii* *P. pratensis* *Vitis arizonica*	Alexander et al. 1984a Fitzhugh et al. 1984
Abies concolor / *Juniperus communis* H.T.	Mountains of southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. pungens* *P. tremuloides* *P. flexilis*	*J. communis* *S. oreophilus* *R. woodsii* *C. rossii* *B. repens*	Youngblood 198
Abies concolor / *Physocarpus malvaceus* H.T.	Mountains of Utah	Warm moist	Seral to *A. concolor*	*A. concolor* *P. tremuloides* *A. grandis* *J. scopulorum*	*P. malvaceus* *Mitella stauropetala* *S. racemosa* *A. alnifolia* *S. oreophilus*	Mauk and Hend son 1984 Youngblood 198
Abies concolor / *Quercus gambelii* H.T. [*A. concolor-Pseudotsuga menziesii* / *Q. gambelii* H.T.]	Mountains of Utah, New Mexico, Arizona, and southern Colorado	Warm dry	Co-climax with *A. concolor*	*A. concolor* *P. tremuloides* *P. ponderosa* *P. strobiformis* *J. scopulorum*	*Q. gambelii* *M. virescens* *F. arizonica* *S. oreophilus* *A. alnifolia* *B. repens* *C. rossii*	Alexander et al. 1984a, 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwi 1979 Youngblood 19
Abies concolor / *Robinia neomexicana* H.T. [*A. concolor-Pseudotsuga menziesii* / *R. neomexicana* H.T.]	Mountains of New Mexico and Arizona	Warm dry	Co-climax with or seral to *A. concolor*	*A. concolor* *P. ponderosa* *P. tremuloides* *P. engelmannii* *P. strobiformis*	*R. neomexicana* *S. oreophilus* *Q. gambelii*	Fitzhugh et al. 1984 Moir and Ludwi 1979
Abies concolor / *Symphoricarpos oreophilus* H.T.	Mountains of central and southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. ponderosa* *P. tremuloides* *J. scopulorum*	*S. oreophilus* *R. woodsii* *A. alnifolia* *C. rossii* *P. fendleriana*	Youngblood 19
Abies concolor / *Vaccinium myrtillus* H.T.	Mountains of northern New Mexico and southern Colorado	Cool dry	Co-climax with *A. concolor*	*A. concolor* *A. lasiocarpa* *P. engelmannii* *P. pungens* *P. tremuloides*	*V. myrtillus* *A. uva-ursi* *P. myrsinites* *A. glabrum* *Rubus parviflorus*	DeVelice et al. 1984
Abies concolor / *Elymus triticoides* H.T. [*A. concolor-Pseudotsuga menziesii* / *E. triticoides* H.T.]	Capitan Mountains, New Mexico	Warm dry	Co-climax with *A. concolor*	*A. concolor* *P. ponderosa* *P. tremuloides* *P. strobiformis*	*E. triticoides* *B. richardsonii*	Alexander et al 1984a Moir and Ludw 1979

able A2.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
ies concolor / Festuca arizonica H.T.	Mountains of northern New Mexico	Warm dry	Co-climax with or seral to *A. concolor*	*A. concolor* *P. ponderosa* *P. tremuloides* *P. strobiformis*	*F. arizonica* *Q. gambelii* *Muhlenbergia* spp. *Poa* spp.	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
bies concolor / Muhlenbergia virescens H.T.	Mountains of eastern Arizona and southwestern New Mexico	Warm dry	Co-climax with *A. concolor*	*A. concolor* *P. ponderosa* *P. strobiformis*	*M. virescens* *Lupinus* spp. *P. fendleriana* *Senecio* spp.	Fitzhugh et al. 1984
bies concolor / Poa fendleriana H.T. *. concolor-Pseudotsuga menziesii / P. fendleriana* H.T.]	White Mountains, Arizona	Warm dry	Co-climax with *A. concolor*	*A. concolor* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*P. fendleriana* *Fragaria vesca* *Senecio wootonii* *A. lanulosa* *G. richardsonii* *Erigeron* spp.	Moir and Ludwig 1979
bies concolor / Carex foenea H.T.	Pinaleno Mountains, Arizona	Warm dry	Seral to *A. concolor*	*A. concolor* *P. ponderosa* *P. strobiformis*	*C. foenea*	Moir and Ludwig 1979
ies concolor / Erigeron eximius H.T. *. concolor-Pseudotsuga menziesii / E. superbus* H.T.]	Mountains of New Mexico and Arizona	Cool moist	Co-climax with *A. concolor*	*A. concolor* *P. ponderosa* *P. tremuloides* *P. pungens* *P. engelmannii* *P. strobiformis*	*E. superbus* (*E. eximius*) *C. foenea* *Lathyrus arizonicus* *P. virginiana*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
ies concolor / Lathyrus arizonicus H.T. *concolor-Pseudotsuga menziesii / L. arizonicus* H.T.]	San Francisco Peaks, Arizona	Cool dry	Co-climax with *A. concolor*	*A. concolor* *P. ponderosa* *P. tremuloides*	*L. arizonicus* *G. richardsonii*	Moir and Ludwig 1979
ies concolor / Osmorhiza chilensis H.T.	Wasatch Mountains, Utah	Warm moist	Seral to *A. concolor*	*A. concolor* *P. tremuloides* *P. engelmannii* *A. grandis*	*O. chilensis* *P. malvaceus* *P. myrsinites* *P. virginiana*	Mauk and Henderson 1984
ies concolor / Scree H.T.	Mountains of southern Colorado and northern New Mexico	Cool dry	Co-climax with *A. concolor*	*A. concolor* *P. strobiformis*	*B. ciliatus* *J. americana* *K. cristata*	DeVelice et al. 1984 Fitzhugh et al. 1984
ies concolor / Sparse H.T. *concolor-Pseudotsuga menziesii* H.T.]	Mountains of New Mexico, Arizona, and southern Colorado	Warm dry	Co-climax with *A. concolor*	*A. concolor* *P. tremuloides* *P. pungens* *P. ponderosa* *P. strobiformis*	*S. oreophilus* *R. neomexicana* *Q. gambelii* *B. repens*	Alexander et al. 1984a DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
***Abies grandis* series**						
es grandis / cer glabrum H.T.	Mountains of central Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* (minor climax) *P. ponderosa*	*A. glabrum* *S. albus* *P. malvaceus* *S. betulifolia* *C. rubescens*	Steele et al. 1981

Table A2.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. menziesii***	**Principal tree associates**	**Principal understory species**	**Authority**
Abies grandis / Linnaea borealis H.T.	Mountains of central and northern Idaho, and southern Montana	Warm moist to well-drained	Seral to *A. grandis*	*A. grandis* *P. ponderosa* *P. engelmannii* *A. lasiocarpa* *P. contorta* *L. occidentalis*	*L. borealis* *X. tenax* *C. rubescens* *A. alnifolia* *A. cordifolia* *Lupinus* spp.	Cooper et al. 198 Pfister et al. 197 Steele et al. 198
Abies grandis / Pachistima myrsinites H.T.	Mountains of northern Idaho and eastern Washington	Warm dry to well-drained	Seral to *A. grandis*	*A. grandis* *P. ponderosa* *L. occidentalis* *P. contorta*	*P. myrsinites* *Bromus vulgaris* *Galium triflorum* *Smilacina stellata* *Thalictrum occidentale*	Daubenmire and Daubenmire 19
Abies grandis / Physocarpus malvaceus H.T.	Mountains of northern Idaho	Warm dry	Seral to *A. grandis*	*A. grandis* *P. ponderosa* *P. contorta* *L. occidentalis*	*P. malvaceus* *A. glabrum* *H. discolor* *S. racemosa*	Cooper et al. 19
Abies grandis / Spiraea betulifolia H.T.	Mountains of central Idaho	Warm dry	Seral to *A. grandis*	*A. grandis* *P. ponderosa* *P. tremuloides*	*S. betulifolia* *S. albus* *A. cordifolia* *C. rubescens*	Steele et al. 198
Abies grandis / Vaccinium caespitosum H.T.	Mountains of central Idaho	Cool moist to well-drained	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. engelmannii* *P. ponderosa* *P. contorta* *L. occidentalis*	*V. caespitosum* *F. virginiana* *C. rubescens*	Steele et al. 198
Abies grandis / Vaccinium globulare H.T.	Mountains of central Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *P. ponderosa* *P. contorta* *A. lasiocarpa* *P. engelmannii* *L. occidentalis*	*V. globulare* *Lonicera utahensis*	Steele et al. 198
Abies grandis / Xerophyllum tenax H.T.	Mountains of northern Idaho and northwestern Montana	Warm dry	Seral to *A. grandis*	*A. grandis* *P. ponderosa* *P. contorta* *L. occidentalis* *A. lasiocarpa* *P. engelmannii*	*X. tenax* *V. globulare* *C. rubescens* *Arnica latifolia* *P. myrsinites*	Cooper et al. 19 Pfister et al. 19
Abies grandis / Calamagrostis rubescens H.T.	Mountains of central Idaho	Cool dry	Seral to *A. grandis*	*A. grandis* *P. contorta* *P. ponderosa* *L. occidentalis*	*C. rubescens* *C. geyeri* *S. betulifolia* *A. cordifolia*	Steele et al. 19
Abies grandis / Clintonia uniflora H.T.	Mountains of northern Montana, and northern and central Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. ponderosa* *P. engelmannii* *Pinus monticola* *L. occidentalis* *P. contorta*	*C. uniflora* *A. glabrum* *V. globulare* *L. borealis* *G. triflorum* *Bromus vulgaris* *P. malvaceus* *X. tenax*	Cooper et al. 19 Pfister et al. 19 Steele et al. 19
Abies grandis / Coptis occidentalis H.T.	Mountains of northern Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *P. ponderosa* *P. contorta* *L. occidentalis* *P. engelmannii* *A. lasiocarpa*	*C. occidentalis* *P. malvaceus* *V. globulare* *X. tenax* *S. albus* *H. discolor*	Cooper et al. 19

Table A2.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
bies grandis / Senecio triangularis H.T.	Mountains of northern Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *L. occidentalis* *P. engelmannii* *A. lasiocarpa*	*S. triangularis* *Athyrium felix-femina* *Trautvettera carolinensis*	Cooper et al. 1983
***Thuja plicata* series**						
huja plicata / Oplopanax horridum H.T.	Mountains of Montana	Cool moist	Seral to *T. plicata* *P. engelmannii*	*T. plicata* *P. engelmannii* *Tsuga heterophylla* *P. monticola* *Tsuga mertensiana*	*O. horridum* *A. felix-femina* *Dryopteris dilatata*	Pfister et al. 1977
huja plicata / Pachistima myrsinites H.T.	Mountains of northern Idaho, and eastern Washington and Oregon	Warm dry to well-drained	Seral to *T. plicata*	*T. plicata* *P. monticola* *L. occidentalis* *P. engelmannii* *P. contorta* *A. grandis*	*P. myrsinites* *A. glabrum* *G. triflorum*	Daubenmire and Daubenmire 1968
huja plicata / Athyrium felix-femina H.T.	Mountains of northern Idaho, and eastern Washington and Oregon	Cool wet	Seral to *T. plicata*	*T. plicata* *P. monticola* *A. grandis* *P. engelmannii*	*A. felix-femina* *G. triflorum*	Cooper et al. 1983 Daubenmire and Daubenmire 1968
huja plicata / Clintonia uniflora H.T.	Mountains of northern Idaho and northwestern Montana	Cool to warm moist	Seral to *T. plicata*	*T. plicata* *A. lasiocarpa* *A. grandis* *P. engelmannii* *L. occidentalis* *P. contorta*	*C. uniflora* *Aralia nudicaulis* *Menziesia ferruginea* *X. tenax* *Asarum caudatum*	Cooper et al. 1983 Pfister et al. 1977
***Picea pungens* series**						
icea pungens / Amelanchier alnifolia H.T.	Mountains of western and central Colorado	Warm moist	Seral to *P. pungens*	*P. pungens* *A. lasiocarpa* *P. angustifolia*	*A. alnifolia* *Cornus stolonifera* *C. geyeri* *Swida sericea*	Hess and Wasser 1982 Komarkova 1984
icea pungens / Arctostaphylos uva-ursi H.T. *. pungens-Pseudotsuga menziesii / A. uva-ursi* H.T.]	Mountains of northern New Mexico and southern Colorado	Warm dry	Co-climax with *P. pungens* *A. concolor*	*P. pungens* *A. concolor* *P. ponderosa* *P. tremuloides* *P. flexilis*	*A. uva-ursi* *J. communis* *F. arizonica* *F. ovalis*	DeVelice et al. 1984 Moir and Ludwig 1979
cea pungens / Berberis repens H.T.	Mountains of Utah	Cool dry	Minor climax to *P. pungens*	*P. pungens* *P. tremuloides* *P. contorta* *P. ponderosa* *J. scopulorum* *P. flexilis*	*B. repens* *J. communis* *P. myrsinites* *Aquilegia caerulea* *Pyrola secunda* *Ribes montigenum* *S. oreophilus*	Mauk and Henderson 1984 Pfister 1972 Youngblood 1984
cea pungens / Cornus stolonifera H.T.	Mountains of north-central and northwestern New Mexico	Warm moist	Co-climax with *P. pungens*	*P. pungens* *P. tremuloides* *Juniperus* spp.	*C. stolonifera* *B. repens* *P. myrsinites* *C. foenea*	Alexander et al. 1984c
cea pungens / Juniperus communis H.T.	Mountains of central Utah	Cool dry	Seral to *P. pungens*	*P. pungens* *P. tremuloides* *P. ponderosa* *P. flexilis* *J. scopulorum*	*J. communis* *A. uva-ursi* *S. oreophilus* *B. repens* *P. myrsinites*	Youngblood 1984

Table A2.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. menziesii***	**Principal tree associates**	**Principal understory species**	**Authority**
Picea pungens / *Linnaea borealis* H.T. [*P. pungens*-*Pseudotsuga menziesii* / *L. borealis* H.T.]	Sangre de Cristo Mountains, southern Colorado and northern New Mexico	Cool well-drained	Co-climax with *P. pungens* *A. concolor*	*P. pungens* *A. concolor* *P. tremuloides* *P. flexilis* *A. lasiocarpa* *P. engelmannii*	*L. borealis* *P. myrsinites* *V. myrtillus* *R. parviflorus*	DeVelice et al. 1984 Moir and Ludwig 1979
Picea pungens / *Agropyron spicatum* H.T.	Uinta Mountains, Utah	Warm dry	Seral to *P. pungens*	*P. pungens* *P. tremuloides* *P. contorta* *P. ponderosa* *P. flexilis* *J. scopulorum*	*A. spicatum* *B. repens* *J. communis* *P. myrsinites*	Mauk and Henderson 1984
Picea pungens / *Festuca arizonica* H.T.	Jemez Mountains, New Mexico; San Juan Mountains, Colorado	Warm dry	Co-climax with *P. pungens*	*P. pungens* *A. concolor* *P. ponderosa* *P. tremuloides*	*F. arizonica* *C. foenea* *Erigeron* spp. *Fragaria* spp.	DeVelice et al. 1984
Picea pungens / *Poa pratensis* H.T.	Mountains of New Mexico	Warm to cool moist	Seral to *P. pungens*	*P. pungens* *P. ponderosa* *P. tremuloides* *A. concolor* *P. strobiformis*	*P. pratensis* *E. superbus* (*E. eximius*) *G. richardsonii* *F. virginiana*	Fitzhugh et al. 1983 Moir and Ludwig 1979
Picea pungens / *Carex foenea* H.T.	White Mountains, Kaibab Plateau, Arizona; Jemez Mountains of northern New Mexico	Warm to cool moist	Co-climax with *P. pungens* *P. ponderosa*	*P. pungens* *P. ponderosa* *A. concolor* *P. tremuloides* *P. strobiformis*	*C. foenea* *F. arizonica* *M. montana* *B. ciliatus* *Fragaria* spp.	Alexander et al. 1984c DeVelice et al. 1984 Moir and Ludwig 1979
Picea pungens / *Arnica cordifolia* H.T.	Front Range, north-central Colorado	Cool moist	Seral to *P. pungens*	*P. pungens* *P. tremuloides*	*A. cordifolia* *S. stellata* *J. communis*	Hess 1981
Picea pungens / *Equisetum arvense* H.T.	Mountains of southern Utah	Warm to cool wet	Seral to *P. pungens*	*P. pungens* *P. engelmannii* *P. tremuloides*	*E. arvense* *G. richardsonii* *Thalictrum fendleri* *O. chilensis*	Youngblood 1984
Picea pungens / *Erigeron eximius* H.T. [*P. pungens*-*Picea engelmannii* / *E. superbus* H.T.]	Mountains of Arizona, northern New Mexico, and southern Colorado	Cool dry	Co-climax with *P. pungens* *P. engelmannii* *A. concolor*	*P. pungens* *P. engelmannii* *A. concolor* *A. lasiocarpa* *P. ponderosa* *P. tremuloides* *P. strobiformis*	*E. superbus* (*E. eximius*) *F. arizonica* *C. foenea* *F. virginiana* *G. richardsonii* *T. fendleri*	DeVelice et al. 1984 Moir and Ludwig 1979
Picea pungens / *Fragaria ovalis* H.T. [*P. pungens*-*Pseudotsuga menziesii* / *Valeriana acutiloba* H.T.]	Mountains of New Mexico and eastern Arizona	Cool moist	Co-climax with *P. pungens*	*P. pungens* *P. ponderosa* *A. concolor* *P. strobiformis* *P. tremuloides* *P. engelmannii* *A. lasiocarpa*	*F. ovalis* *V. acutiloba* *C. foenea* *F. arizonica* *E. superbus* (*E. eximius*)	Alexander et al. 1984a Fitzhugh et al. 1984 Moir and Ludwig 1979
Picea pungens / *Senecio cardamine* H.T. [*P. pungens*-*Picea engelmannii* / *S. cardamine* H.T.]	White Mountains, Arizona	Cool moist	Seral to *P. pungens* *P. engelmannii* *A. lasiocarpa*	*P. pungens* *P. engelmannii* *A. lasiocarpa* *A. concolor* *P. ponderosa* *P. tremuloides* *P. strobiformis*	*S. cardamine* *P. aquilinum* *Helenium hoopesii* *Viola canadensis*	Moir and Ludwig 1979

Table A2.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
			***Populas tremuloides* series and other *P. tremuloides* dominated vegetation**			
opulus tremuloides-Pseudotsuga menziesii / Amelanchier alnifolia C.T., *. tremuloides / A. alnifolia* C.T.	Mountains of southeastern Idaho	Warm dry	Climax or ultimate climax unknown	*P. tremuloides*	*A. alnifolia* *P. virginiana* *P. myrsinites* *S. oreophilus* *S. betulifolia* *C. rubescens*	Mueggler and Campbell 1982
opulus tremuloides / Pachistima myrsinites C.T.	Mountains of southeastern Idaho	Warm dry	Ultimate climax unknown. Probably *P. menziesii* *A. lasiocarpa* *P. engelmannii*	*P. tremuloides* *A. lasiocarpa* *P. engelmannii*	*P. myrsinites* *C. rubescens* *S. oreophilus* *Lupinus argenteus*	Mueggler and Campbell 1982
opulus tremuloides-Abies lasiocarpa / Prunus virginiana C.T., *. tremuloides / P. virginiana* C.T.	Mountains of western Wyoming	Warm dry	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides*	*P. virginiana* *B. repens* *S. oreophilus* *R. woodsii*	Youngblood and Mueggler 1981
opulus tremuloides-Pseudotsuga menziesii / Spiraea betulifolia C.T., *. tremuloides / S. betulifolia* C.T.	Mountains of southeastern Idaho and western Wyoming	Warm dry	Climax	*P. tremuloides*	*S. betulifolia* *A. alnifolia* *B. repens* *C. rubescens*	Mueggler and Campbell 1982 Youngblood and Mueggler 1981
opulus tremuloides-Abies lasiocarpa / Symphoricarpos oreophilus C.T., *tremuloides / S. oreophilus* H.T. (CO); C.T.(WY,ID,UT)	Mountains of southeastern Idaho, northern Utah, western Wyoming, northern and central Colorado	Warm well-drained	Seral to *A. lasiocarpa* or ultimate climax unknown	*A. lasiocarpa* *A. concolor* *P. tremuloides*	*S. oreophilus* *P. virginiana* *B. repens* *Elymus glaucus* *Geranium viscosissimum* *L. argenteus*	Hess and Wasser 1982 Mauk and Henderson 1984 Mueggler and Campbell 1982 Steele et al. 1983 Youngblood and Mueggler 1981
opulus tremuloides-Pseudotsuga menziesii / Symphoricarpos oreophilus C.T., *tremuloides / S. oreophilus* C.T.	Mountains of southeastern Idaho	Warm dry	Climax	*P. tremuloides* *A. lasiocarpa* *P. contorta*	*S. oreophilus* *C. rubescens* *P. pratensis* *Rudbeckia occidentalis* *C. geyeri*	Mueggler and Campbell 1982
pulus tremuloides-Pseudotsuga menziesii / Calamagrostis rubescens C.T., *tremuloides / C. rubescens* C.T.	Mountains of southeastern Idaho and western Wyoming	Warm dry	Climax	*P. tremuloides* *P. contorta*	*C. rubescens* *S. oreophilus* *T. fendleri* *A. cordifolia*	Mueggler and Campbell 1982 Youngblood and Mueggler 1981
pulus tremuloides-Pinus contorta / Calamagrostis rubescens .T., *tremuloides / C. rubescens* C.T.	Mountains of southeastern Idaho	Warm dry	Ultimate climax unknown. Probably *A. lasiocarpa* or *P. menziesii*	*A. lasiocarpa* *P. contorta* *P. tremuloides*	*C. rubescens* *S. oreophilus* *P. myrsinites* *L. argenteus* *T. fendleri*	Mueggler and Campbell 1982
pulus tremuloides / Festuca thurberi H.T.	Mountains of northern and central Colorado	Warm dry	Ultimate climax unknown	*P. tremuloides* *P. contorta* *P. engelmannii* *A. lasiocarpa*	*F. thurberi* *B. repens* *S. oreophilus* *F. ovalis*	Hess 1981 Hess and Wasser 1982

Table A2.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
Populus tremuloides / Poa pratensis C.T.	Mountains of southeastern Idaho	Warm dry	Ultimate climax unknown. Probably *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. tremuloides*	*P. pratensis* *G. viscosissimum* *C. rubescens* *T. fendleri* *L. argenteus*	Mueggler and Campbell 1982
Populus tremuloides-Abies lasiocarpa / Pedicularis racemosa C.T.	Mountains of western Wyoming	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*P. racemosa* *A. cordifolia* *S. oreophilus*	Youngblood and Mueggler 1981
Populus tremuloides / Thalictrum fendleri H.T. (CO)	Mountains of northern and central Colorado	Warm moist	Ultimate climax unknown	*P. tremuloides* *P. flexilis* *P. contorta*	*T. fendleri* *C. geyeri* *E. glaucus*	Hess 1981 Hess and Wasse 1982
			***Pinus contorta* series and other *P. contorta* dominated vegetation**			
Pinus contorta / Juniperus communis H.T.(CO); C.T.(ID,UT,WY)	Mountains of eastern Idaho, northern Utah, northwestern Wyoming, and central Colorado	Warm dry	Seral to *P. contorta* (CO). Ultimate climax unknown (ID,UT,WY)	*P. contorta* *P. tremuloides* *Pinus albicaulis* *P. engelmannii* *A. lasiocarpa*	*J. communis* *A. uva-ursi* *S. canadensis* *A. cordifolia*	Hess 1981 Mauk and Hende son 1984 Steele et al. 198
Pinus contorta / Linnaea borealis C.T.	Mountains of Montana east of Continental Divide, and northwestern Wyoming	Cool moist to well-drained	Ultimate climax unknown	*A. lasiocarpa* *P. engelmannii* *P. contorta*	*L. borealis* *V. scoparium* *V. globulare* *A. cordifolia* *C. rubescens*	Pfister et al. 197 Steele et al. 198
Pinus contorta / Purshia tridentata H.T.	Mountains of western Montana	Cool-warm dry to well-drained	Ultimate climax unknown. May be *P. contorta*	*P. contorta* *P. engelmannii* *A. lasiocarpa* *P. tremuloides*	*P. tridentata* *A. uva-ursi* *C. rossii* *A. spicatum* *Lupinus* spp.	Pfister et al. 197
Pinus contorta / Shepherdia canadensis C.T.	Mountains of southeastern Idaho and northwestern Wyoming	Cool-warm dry to well-drained	Ultimate climax unknown	*P. contorta* *P. engelmannii* *P. tremuloides* *A. lasiocarpa* *P. albicaulis*	*S. canadensis* *A. cordifolia* *J. communis* *A. uva-ursi*	Steele et al. 198
Pinus contorta / Spiraea betulifolia C.T.	Mountains of eastern Idaho to northwestern Wyoming	Warm dry	Ultimate climax unknown	*P. contorta* *A. lasiocarpa* *P. engelmannii*	*S. betulifolia* *C. rubescens* *C. geyeri*	Steele et al. 198
Pinus contorta / Vaccinium caespitosum C.T.	Mountains of south-central Montana, Idaho, and northern Utah	Cool well-drained	Ultimate climax unknown	*P. contorta* *A. lasiocarpa* *P. engelmannii*	*V. caespitosum* *V. scoparium* *Festuca ovina* *L. borealis*	Cooper et al. 19 Pfister et al. 19 Steele et al. 19
Pinus contorta / Vaccinium globulare C.T.	Mountains of southern Idaho, northwestern Wyoming, and northern Utah	Cool well-drained	Ultimate climax unknown	*P. contorta* *P. engelmannii* *A. lasiocarpa*	*V. globulare* *L. utahensis* *V. scoparium* *C. rubescens*	Steele et al. 19
Pinus contorta / Vaccinium scoparium H.T. (CO,WY); C.T.(ID,UT,MT)	Bighorn Mountains, Wyoming; mountains of central Colorado, Montana, Idaho, and northern Utah	Cool to cold dry	Seral to *P. contorta* (CO,WY) or ultimate climax unknown (ID, UT, MT)	*P. contorta* *P. engelmannii* *A. lasiocarpa* *A. grandis* *L. occidentalis*	*V. scoparium* *A. cordifolia* *J. communis* *L. borealis* *C. rubescens* *B. repens* *C. geyeri*	Cooper et al. 19 Hess 1981 Hoffman and Al ander 1976 Pfister et al. 19 Steele et al. 19

able A2.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
nus contorta / Xerophyllum tenax C.T.	Mountains of northern Idaho	Warm dry	Ultimate climax unknown. Probably seral or minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. engelmannii*	*X. tenax* *Vaccinium* spp.	Cooper et al. 1983
nus contorta / Calamagrostis rubescens C.T.	Mountains of Montana, Idaho, northeastern Utah, and northwestern Wyoming	Warm dry	Ultimate climax unknown	*P. contorta* *P. engelmannii* *A. lasiocarpa* *L. occidentalis*	*C. rubescens* *V. scoparium* *C. geyeri* *A. cordifolia* *A. uva-ursi*	Pfister 1977 Steele et al. 1981, 1983
nus contorta / Festuca idahoensis H.T.	Mountains of central Idaho	Warm dry to well-drained	Seral to *P. contorta*	*P. contorta* *P. albicaulis*	*F. idahoensis* *C. rossii*	Steele et al. 1981
nus contorta / Carex geyeri C.T.	Mountains of central Idaho	Cool dry	Ultimate climax unknown	*P. contorta* *P. engelmannii* *A. lasiocarpa*	*C. geyeri* *S. oreophilus* *A. cordifolia* *J. communis*	Steele et al. 1981
nus contorta / Geranium fremontii H.T.	Front Range, Colorado	Warm dry	Seral to *P. contorta*	*P. contorta*	*G. fremontii* *A. uva-ursi* *J. communis*	Moir 1969
***Tsuga heterophylla* series**						
uga heterophylla / Pachistima myrsinites H.T.	Mountains of northern Idaho and eastern Washington	Warm moist	Seral to *T. heterophylla*	*T. heterophylla* *T. plicata* *L. occidentalis* *A. grandis* *P. monticola*	*P. myrsinites* *C. uniflora* *L. borealis* *Vaccinium membranaceum*	Daubenmire and Daubenmire 1968
uga heterophylla / Clintonia uniflora H.T.	Mountains of northern Idaho and northwestern Montana	Warm moist	Seral to *T. heterophylla* *T. plicata*	*T. heterophylla* *T. plicata* *P. monticola* *P. engelmannii* *A. lasiocarpa* *L. occidentalis* *P. contorta* *A. grandis*	*C. uniflora* *A. nudicaulis* *M. ferruginea* *X. tenax* *A. caudatum*	Cooper et al. 1983 Pfister et al. 1977
***Picea engelmannii* series**						
ea engelmannii / cer glabrum H.T.	Chiricahua and Sacramento Mountains, Arizona and New Mexico	Warm moist	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* *P. tremuloides*	*A. glabrum* *B. ciliatus* *V. canadensis* *S. stellata*	Alexander et al. 1984a Moir and Ludwig 1979
ea engelmannii / uniperus communis H.T.	Wind River and Absaroka Mountains, northwestern Wyoming	Warm dry	Seral to *P. engelmannii*	*P. engelmannii* *P. flexilis* *P. albicaulis* *P. contorta*	*J. communis* *A. cordifolia* *Frasera speciosa*	Steele et al. 1983
ea engelmannii / innaea borealis H.T.	Mountains of Montana east of Continental Divide and Wind River Mountains, Wyoming	Cool well-drained	Seral to *P. engelmannii*	*P. engelmannii* *P. contorta*	*L. borealis* *V. globulare* *S. albus* *J. communis*	Pfister et al. 1977 Steele et al. 1983

Table A2.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
Picea engelmannii / Physocarpus malvaceus H.T.	Mountains of south-central Montana, eastern Idaho, and northwestern Wyoming	Warm moist	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* (minor climax) *P. contorta*	*P. malvaceus* *G. triflorum* *S. albus* *S. betulifolia*	Pfister et al. 197 Steele et al. 1983
Picea engelmannii / Vaccinium caespitosum H.T.	Mountains of northwest Montana	Cool well-drained	Seral to *P. engelmannii*	*P. engelmannii* *L. occidentalis* *P. ponderosa* *P. contorta*	*V. caespitosum* *L. borealis* *V. scoparium* *C. rubescens* *R. montigenum*	Pfister et al. 197
Picea engelmannii / Vaccinium scoparium H.T.	Bighorn Mountains, north-central Wyoming	Cool dry	Seral to *P. engelmannii*	*P. engelmannii* *P. contorta*	*V. scoparium* *A. cordifolia* *C. rossii* *Antennaria* spp. *F. virginiana*	Hoffman and Ale ander 1976
Picea engelmannii / Bromus ciliatus H.T.	Mogollon and Black Mountains, New Mexico	Cool dry	Seral to *P. engelmannii*	*P. engelmannii*	*B. ciliatus* *G. richardsonii* *L. arizonicus* *S. stellata* *V. canadensis*	Fitzhugh et al. 1984
Picea engelmannii / Elymus triticoides H.T.	Capitan Mountains, New Mexico	Cool dry to well-drained	Seral to *P. engelmannii* *A. lasiocarpa*	*P. engelmannii* *A. lasiocarpa* *P. tremuloides*	*E. triticoides* *A. glabrum* *J. americana*	Alexander 1984 Moir and Ludwi 1979
Picea engelmannii / Arnica cordifolia H.T.	Mountains of northwestern Wyoming	Cool well-drained	Seral to *P. engelmannii*	*P. engelmannii* *P. flexilis* *P. albicaulis* *P. tremuloides* *P. contorta*	*A. cordifolia* *C. rossii* *A. miser* *F. speciosa*	Steele et al. 19
Picea engelmannii / Clintonia uniflora H.T.	Mountains of northwestern Montana	Warm moist to dry	Seral to *P. engelmannii*	*P. engelmannii* *P. contorta* *P. ponderosa* *L. occidentalis*	*C. uniflora* *V. caespitosum* *A. nudicaulis* *Calamagrostis canadensis*	Pfister et al. 19
Picea engelmannii / Galium triflorum H.T.	Mountains of south-central Montana, and western Wyoming	Warm moist	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* *P. contorta* *P. pungens* *P. ponderosa*	*G. triflorum* *Actaea rubra* *S. stellata* *S. amplexifolius*	Pfister et al. 19 Steele et al. 19
Picea engelmannii / Hypnum revolutum H.T.	Mountains of southeastern Idaho and northwestern Wyoming	Cool dry	Seral to *P. engelmannii*	*P. engelmannii* *P. flexilis* *P. albicaulis*	*H. revolutum* *Dicranowiesia crispula*	Steele et al. 19 1983
Picea engelmannii / Senecio cardamine H.T.	Blue Mountains, Arizona	Cool moist	Seral to *P. engelmannii*	*P. engelmannii* *P. pungens* *P. ponderosa* *P. strobiformis* *A. lasiocarpa* *A. concolor* *P. tremuloides*	*S. cardamine* *F. ovalis* *G. richardsonii* *V. canadensis*	Fitzhugh et al. 1984
Picea engelmannii / Senecio streptanthifolius H.T.	Mountains of central and southwestern Montana	Cool dry to well-drained	Seral to *P. engelmannii*	*P. engelmannii* *P. flexilis* *P. albicaulis*	*S. streptanthifolius* *P. secunda* *A. cordifolia*	Pfister et al. 1

able A2.—(continued)

labitat type, ommunity type, or lant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
cea engelmannii / Smilacina stellata H.T.	Mountains of Montana east of Continental Divide	Warm moist	Seral to *P. engelmannii*	*P. engelmannii* *P. contorta* *P. ponderosa*	*S. stellata* *S. racemosa* *T. occidentale*	Pfister et al. 1977
cea engelmannii / Moss spp. H.T.	Mountains of north-central and northwestern New Mexico	Cool moist	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* *P. tremuloides* *P. aristata*	Moss spp. *A. glabrum* *J. americana* *E. superbus* (*E. eximius*)	Alexander et al. 1984c Fitzhugh et al. 1984 Moir and Ludwig 1979
			***Abies lasiocarpa* series**			
bies lasiocarpa / Acer glabrum H.T.	Mountains of central and southern Idaho, northern and central Utah, and western Wyoming; mountains of north-central and northwestern New Mexico	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides* *A. concolor* *P. pungens* (UT)	*A. glabrum* *T. occidentale* *T. fendleri* *O. chilensis* *A. alnifolia* *B. repens* *B. ciliatus*	Alexander et al. 1984c Mauk and Henderson 1984 Steele et al. 1981, 1983 Youngblood 1984
bies lasiocarpa / Alnus sinuata H.T.	Mountains of northern Montana and central Idaho	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *L. occidentalis*	*A. sinuata* *X. tenax* *V. scoparium* *V. globulare*	Pfister et al. 1977 Steele et al. 1981
ies lasiocarpa / Berberis repens H.T.	Mountains of Utah, northwestern Wyoming, and southeastern Idaho	Warm-cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. pungens* *P. flexilis* *A. concolor* *P. tremuloides*	*B. repens* *R. montigenum* *C. geyeri* *P. myrsinites* *S. oreophilus*	Mauk and Henderson 1984 Pfister 1972 Steele et al. 1983 Youngblood 1984
ies lasiocarpa / Clematis pseudoalpina H.T.	Mountains of Montana east of Continental Divide	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. flexilis* *P. engelmannii* *P. contorta* *P. albicaulis*	*C. pseudoalpina* *Clematis tenuiloba*	Pfister et al. 1977
ies lasiocarpa / Juniperus communis H.T.	Mountains of central Idaho, northwestern Wyoming, and northern Utah; mountains of northern Arizona and New Mexico	Warm to cold dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides* *A. concolor* (NM,AZ) *P. longaeva* (UT) *P. pungens* (UT)	*J. communis* *P. secunda* *S. canadensis* *A. cordifolia* *S. oreophilus* *R. woodsii*	Mauk and Henderson 1984 Moir and Ludwig 1979 Steele et al. 1981, 1983 Youngblood 1984
ies lasiocarpa / Linnaea borealis H.T.	Mountains of Montana, central and southern Idaho, and western Wyoming	Cool moist to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides* *P. ponderosa* *L. occidentalis*	*L. borealis* *V. scoparium* *C. rubescens* *A. cordifolia* *R. parviflorus*	Pfister et al. 1977 Steele et al. 1981, 1983
ies lasiocarpa / Menziesia ferruginea H.T.	Mountains of Montana and Idaho	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *L. occidentalis* *P. monticola* *P. albicaulis*	*M. ferruginea* *V. globulare* *A. latifolia*	Pfister et al. 1977 Steele et al. 1981

Table A2.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / Oplopanax horridum H.T.	Mountains of northern Montana	Cool moist to wet	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. monticola* *L. occidentalis*	*O. horridum* *Taxus brevifolia*	Pfister et al. 197
Abies lasiocarpa / Pachistima myrsinites H.T., *A. lasiocarpa-Picea engelmannii / P. myrsinites* H.T.	Mountains of northern Idaho and eastern Washington; mountains of central Colorado	Warm dry to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. monticola* *L. occidentalis* *P. tremuloides*	*P. myrsinites* *C. uniflora* *G. triflorum* *C. geyeri* *Erigeron* spp.	Daubenmire and Daubenmire 19 Hess and Wasse 1982
Abies lasiocarpa / Physocarpus malvaceus H.T.	Mountains of eastern Idaho, northwestern Wyoming, and northern and central Utah	Warm moist	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *A. concolor*	*P. malvaceus* *S. albus* *S. betulifolia* *A. alnifolia* *Sorbus scopulina*	Mauk and Hende son 1984 Steele et al. 1983 Youngblood 1984
Abies lasiocarpa / Ribes montigenum H.T.	Mountains of Utah	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*R. montigenum* *A. latifolia* *T. fendleri* *Mertensia arizonica*	Mauk and Hende son 1984 Youngblood 1984
Abies lasiocarpa / Rubus parviflorus H.T.	Mimbres and Mogollon Mountains, New Mexico; San Juan Mountains, Colorado	Warm moist	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *A. concolor* *P. tremuloides*	*R. parviflorus* *V. myrtillus* *A. glabrum*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies lasiocarpa / Shepherdia canadensis H.T.	Bighorn Mountains, north-central Wyoming	Cool to warm dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*S. canadensis* *V. scoparium*	Hoffman and Ale ander 1976
Abies lasiocarpa / Spiraea betulifolia H.T.	Mountains of central and southern Idaho and western Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. albicaulis*	*S. betulifolia* *P. myrsinites* *C. rubescens*	Steele et al. 1981 1983
Abies lasiocarpa / Symphoricarpos albus H.T.	Mountains of southeastern Idaho and western Wyoming	Warm well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*S. albus* *A. alnifolia* *C. rubescens*	Steele et al. 1983
Abies lasiocarpa / Vaccinium caespitosum H.T.	Mountains of central Idaho, northern and central Utah	Cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*V. caespitosum* *L. borealis* *C. rubescens* *V. scoparium* *A. cordifolia*	Mauk and Hender son 1984 Steele et al. 1981
Abies lasiocarpa / Vaccinium globulare H.T.	Mountains of south-central Montana, central Idaho, northern Utah, and northwestern Wyoming	Moist to cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*V. globulare* *V. scoparium* *L. utahensis* *P. myrsinites* *A. cordifolia*	Mauk and Hender son 1984 Pfister et al. 1977 Steele et al. 1981 1983

Table A2.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / Vaccinium myrtillus H.T. *A. lasiocarpa / V. myrtillus-Linnaea borealis* H.T.] *A. lasiocarpa / V. myrtillus-Rubus parviflorus* H.T.] *A. lasiocarpa / Vaccinium scoparium-L. borealis* H.T.]	Mogollon Plateau, Arizona; mountains of northern New Mexico and southern Colorado	Cool moist to well-drained	Seral to *A. lasiocarpa* (AZ) *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *A. concolor* *P. pungens* *P. flexilis* *P. aristata*	*V. myrtillus* *Disporum trachycarpum* *C. canadensis* *Polemonium flavum* *V. scoparium*	Alexander et al. 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies lasiocarpa / Vaccinium scoparium H.T.	Mountains of Montana and Idaho, south to Arizona, and New Mexico	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *L. occidentalis* *P. tremuloides* *P. albicaulis*	*V. scoparium* *C. rubescens* *V. myrtillus* *A. cordifolia* *C. geyeri* *E. superbus* (*E. eximius*) *Polemonium delicatum* *L. borealis* *P. myrsinites*	Hoffman and Alexander 1976 Mauk and Henderson 1984 Moir and Ludwig 1979 Pfister 1972 Pfister et al. 1977 Steele et al. 1981, 1983
bies lasiocarpa / Xerophyllum tenax H.T.	Mountains of northern Idaho and eastern Washington and Oregon, south to southern Idaho, Montana and western Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. albicaulis* *P. contorta* *P. ponderosa*	*X. tenax* *V. membranaceum* *V. scoparium* *V. globulare*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981, 1983
bies lasiocarpa / Calamagrostis canadensis H.T.	Mountains of central and southern Idaho	Cool wet	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*C. canadensis* *G. triflorum* *V. caespitosum* *Ledum glandulosum* *S. triangularis*	Steele et al. 1981
bies lasiocarpa / Calamagrostis rubescens H.T.	Mountains of Montana east of Continental Divide, central and southern Idaho, northern Utah, and northwestern Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*C. rubescens* *O. chilensis* *T. occidentale* *C. geyeri* *A. cordifolia* *P. myrsinites*	Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983
bies lasiocarpa / Carex geyeri H.T.	Mountains of central Montana and central Idaho	Warm to cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. albicaulis*	*C. geyeri* *S. oreophilus* *A. cordifolia* *L. argenteus*	Pfister et al. 1977 Steele et al. 1981
bies lasiocarpa / Carex rossii H.T.	Mountains of central and southern Utah	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*C. rossii* *A. cordifolia* *A. miser* *R. woodsii*	Youngblood 1984
bies lasiocarpa / Aconitum columbianum H.T.	Mountains of central and southern Utah	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *A. concolor*	*A. columbianum* *Actaea rubra* *A. cordifolia* *B. ciliatus*	Youngblood 1984
bies lasiocarpa / Actaea rubra H.T.	Mountains of central Idaho, northern Utah, and western Wyoming	Warm moist	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. pungens* *P. contorta* *P. tremuloides*	*A. rubra* *O. chilensis* *L. utahensis* *V. globulare*	Mauk and Henderson 1984 Steele et al. 1983

Table A2.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. menziesii*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / Arnica cordifolia H.T.	Mountains of Montana, east of Continental Divide, central Idaho, western and north-central Wyoming	Cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. albicaulis* *P. tremuloides*	*A. cordifolia* *P. secunda* *A. miser* *F. virginiana*	Hoffman and Ale ander 1976 Pfister et al. 197 Steele et al. 198 1983
Abies lasiocarpa / Arnica latifolia H.T.	Mountains of southern Idaho, northern Utah, and northwestern Wyoming	Cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides* *P. albicaulis*	*A. latifolia* *Aster engelmannii* *Pedicularis racemosa*	Steele et al. 198
Abies lasiocarpa / Clintonia uniflora H.T.	Mountains of northwestern Montana, northern and central Idaho	Warm moist to dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *L. occidentalis* *P. contorta* *A. grandis* *P. ponderosa*	*C. uniflora* *X. tenax* *M. ferruginea* *V. caespitosum* *A. nudicaulis*	Cooper et al. 198 Pfister et al. 197 Steele et al. 1981
Abies lasiocarpa / Coptis occidentalis H.T.	Mountains of central and northern Idaho	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *A. grandis* *L. occidentalis*	*C. occidentalis* *X. tenax* *V. globulare* *M. ferruginea*	Cooper et al. 198 Steele et al. 1981
Abies lasiocarpa / Erigeron superbus (*E. eximius*) H.T.	Mountains southwest Colorado, New Mexico, and Arizona	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *A. concolor* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*E. superbus* (*E. eximius*) *G. richardsonii* *L. arizonicus* *Lonicera involucrata* *A. cordifolia*	Alexander et al. 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies lasiocarpa / Galium triflorum H.T.	Mountains of Montana	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *L. occidentalis*	*G. triflorum* *A. rubra* *S. amplexifolius*	Pfister et al. 1977
Abies lasiocarpa / Lathyrus arizonicus H.T. [*A. lasiocarpa-Pinus strobiformis / L. arizonicus* H.T.]	Mogollon Mountains, New Mexico	Cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. strobiformis*	*L. arizonicus* *A. glabrum* *S. oreophilus* *V. americana*	Fitzhugh et al. 1984
Abies lasiocarpa / Osmorhiza chilensis H.T.	Mountains of southern Idaho	Warm moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*O. chilensis* *C. rossii* *B. repens* *P. myrsinites*	Steele et al. 1983
Abies lasiocarpa / Pedicularis racemosa H.T.	Mountains of southeastern Idaho, northwestern Wyoming, and northern Utah	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*P. racemosa* *A. cordifolia* *S. oreophilus*	Mauk and Henderson 1984 Steele et al. 1983
Abies lasiocarpa / Saxifraga bronchialis H.T. (Scree Forest)	Mogollon Mountains, New Mexico	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. strobiformis*	*S. bronchialis* *S. oreophilus* *J. communis* *H. dumosus*	Fitzhugh et al. 1984

Table A2.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. menziesii***	**Principal tree associates**	**Principal understory species**	**Authority**
bies lasiocarpa / Senecio sanguisorboides H.T.	Sacramento Mountains, New Mexico	Cool dry to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*S. sanguisorboides* *R. montigenum* *Ribes wolfii*	Alexander et al. 1984a Moir and Ludwig 1979
bies lasiocarpa / Thalictrum occidentale H.T.	Mountains of southeastern Idaho and northwestern Wyoming	Warm well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*T. occidentale* *O. chilensis* *A. cordifolia*	Steele et al. 1983
bies lasiocarpa / Moss spp. H.T.	Mountains of northern New Mexico and southern Colorado	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *P. aristata*	Moss spp. *Vaccinium* spp. *J. communis* *A. glabrum*	DeVelice et al. 1984
			***Tsuga mertensiana* series**			
suga mertensiana / Menziesia ferruginea H.T.	Mountains of western Montana	Cool moist	Seral to *T. mertensiana*	*T. mertensiana* *P. engelmannii* *A. lasiocarpa* *P. contorta* *L. occidentalis*	*M. ferruginea* *Rhododendron albiflorum* *X. tenax*	Pfister et al. 1977
suga mertensiana / Xerophyllum tenax H.T.	Mountains of northern Idaho, northwestern Montana, mountains of British Columbia south to central Oregon	Cool dry	Seral to *T. mertensiana*	*T. mertensiana* *P. contorta* *A. lasiocarpa* *P. engelmannii* *P. albicaulis* *P. monticola* *L. occidentalis*	*X. tenax* *V. membranaceum* *V. globulare*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Pfister et al. 1977
suga mertensiana / Clintonia uniflora H.T.	Mountains of northern Idaho	Cool moist	Seral to *T. mertensiana*	*T. mertensiana* *P. contorta* *P. engelmannii* *A. lasiocarpa* *A. grandis*	*C. uniflora* *M. ferruginea* *X. tenax*	Cooper et al. 1983
suga mertensiana / Streptopus amplexifolius H.T.	Mountains of northern Idaho	Cool moist	Seral to *T. mertensiana*	*T. mertensiana* *L. occidentalis* *P. engelmannii* *A. lasiocarpa*	*S. amplexifolius* *S. triangularis* *T. carolinensis* *Veratrum viride*	Cooper et al. 1983

Table A3.—Habitat types, community types, and plant communities in which interior *Abies concolor* is climax, co-climax, minor climax, or seral.

Habitat type, community type, or plant community	Location	Site	Successional status of *A. concolor*	Principal tree associates	Principal understory species	Authority
			***Abies concolor* series**			
Abies concolor / Acer glabrum H.T. [*A. concolor-Pseudotsuga menziesii / A. glabrum* H.T.]	Mountains of southern Utah, New Mexico, Arizona, and southern Colorado	Warm moist to well-drained	Climax or co-climax with *P. menziesii*	*P. menziesii* *Populus tremuloides* *Pinus strobiformis* *Picea pungens* *Picea engelmannii* *Pinus ponderosa* (NM) *Abies lasiocarpa*	*A. glabrum* *Berberis repens* *Quercus gambelii* *Holodiscus dumosus* *Pachistima myrsinites* *Prunus virginiana* *Amelanchier alnifolia*	Alexander et al. 1984a, 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwi 1979 Youngblood 198
Abies concolor / Acer grandidentatum H.T.	Mountains of northern Arizona and New Mexico	Cool moist to warm well-drained	Climax	*P. menziesii* *P. ponderosa* (AZ) *P. tremuloides* *P. strobiformis*	*A. grandidentatum* *Q. gambelii* *Carex foenea* *H. dumosus*	Alexander et al. 1984a Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies concolor / Arctostaphylos patula H.T.	Mountains of southern Utah	Warm dry	Climax	*P. menziesii* *P. pungens* *P. ponderosa* *Pinus flexilis* *Juniperus scopulorum*	*A. patula* *Juniperus communis* *Symphoricarpos oreophilus* *Rosa woodsii*	Youngblood 198
Abies concolor / Arctostaphylos uva-ursi H.T.	Mountains of northern New Mexico and southern Colorado	Warm dry	Co-climax with *P. menziesii*	*P. menziesii* *P. ponderosa* *P. tremuloides* *P. flexilis*	*A. uva-ursi* *P. myrsinites*	DeVelice et al. 1984
Abies concolor / Berberis repens H.T.	Mountains of Utah	Warm dry	Climax	*P. menziesii* *Pinus contorta* *P. flexilis* *Abies grandis* *P. tremuloides* *P. ponderosa* *P. pungens*	*B. repens* *S. oreophilus* *Osmorhiza* spp. *Lathyrus leucanthus* *J. communis* *R. woodsii* *P. myrsinites*	Mauk and Hende son 1984 Youngblood 1984
Abies concolor / Cercocarpus ledifolius H.T.	Mountains of central and southern Utah	Warm dry	Climax	*P. menziesii* *P. ponderosa* *P. flexilis* *J. scopulorum*	*C. ledifolius* *Q. gambelii* *A. alnifolia* *B. repens* *S. oreophilus*	Youngblood 1984
Abies concolor / Juglans major H.T.	Mountains of southern New Mexico	Warm moist	Climax	*P. menziesii* *P. tremuloides* *Populus angustifolia* *Fraxinus pensylvanica*	*J. major* *Q. gambelii* *Poa pratensis* *Vitis arizonica*	Alexander et al. 1984a Fitzhugh et al. 1984
Abies concolor / Juniperus communis H.T.	Mountains of southern Utah	Warm dry	Climax	*P. menziesii* *P. pungens* *P. tremuloides* *P. flexilis*	*J. communis* *S. oreophilus* *R. woodsii* *B. repens* *Carex rossii*	Youngblood 1984
Abies concolor / Physocarpus malvaceus H.T.	Mountains of Utah	Warm moist	Climax	*P. menziesii* *P. tremuloides* *A. grandis* *J. scopulorum*	*P. malvaceus* *Mitella stauropetala* *Smilacina racemosa* *A. alnifolia* *S. oreophilus*	Mauk and Hender son 1984 Youngblood 1984

Table A3.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *A. concolor***	**Principal tree associates**	**Principal understory species**	**Authority**
Abies concolor / Quercus gambelii H.T. *A. concolor-Pseudotsuga menziesii / Q. gambelii* H.T.]	Mountains of Utah, New Mexico, Arizona, and southern Colorado	Warm dry	Climax or co-climax with *P. menziesii*	*P. menziesii* *P. tremuloides* *P. ponderosa* *P. strobiformis* *J. scopulorum*	*Q. gambelii* *Muhlenbergia virescens* *Festuca arizonica* *S. oreophilus* *A. alnifolia* *B. repens* *C. rossii*	Alexander et al. 1984a, 1984c Fitzhugh et al. 1984 DeVelice et al. 1984 Moir and Ludwig 1979 Youngblood 1984
Abies concolor / Robinia neomexicana H.T. *A. concolor-Pseudotsuga menziesii / R. neomexicana* H.T.]	Mountains of Arizona and New Mexico	Warm dry	Climax or co-climax with *P. menziesii*	*P. menziesii* *P. tremuloides* *P. strobiformis* *P. ponderosa* *P. engelmannii*	*R. neomexicana* *S. oreophilus* *Q. gambelii*	Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies concolor / Symphoricarpos oreophilus H.T.	Mountains of central and southern Utah	Warm dry	Climax	*P. menziesii* *P. ponderosa* *P. tremuloides* *J. scopulorum*	*S. oreophilus* *R. woodsii* *A. alnifolia* *C. rossii* *Poa fendleriana*	Youngblood 1984
Abies concolor / Vaccinium myrtillus H.T.	Mountains of northern New Mexico and southern Colorado	Cool dry	Co-climax with *P. menziesii*	*P. menziesii* *A. lasiocarpa* *P. engelmannii* *P. pungens* *P. tremuloides*	*V. myrtillus* *A. uva-ursi* *P. myrsinites* *A. glabrum* *Rubus parviflorus*	DeVelice et al. 1984
Abies concolor / Elymus triticoides H.T. *A. concolor-Pseudotsuga menziesii / E. triticoides* H.T.]	Capitan Mountains, New Mexico	Warm dry	Co-climax with *P. menziesii*	*P. menziesii* *P. ponderosa* *P. tremuloides* *P. strobiformis*	*E. triticoides* *Bromus richardsonii*	Alexander et al. 1984a Moir and Ludwig 1979
Abies concolor / Festuca arizonica H.T.	Mountains of northern New Mexico	Warm dry	Climax to co-climax with *P. menziesii*	*P. menziesii* *P. ponderosa* *P. tremuloides* *P. strobiformis*	*F. arizonica* *Q. gambelii* *Muhlenbergia* spp. *Poa* spp.	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies concolor / Muhlenbergia virescens H.T.	Mountains of eastern Arizona and southwestern New Mexico	Warm dry	Co-climax with *P. menziesii*	*P. menziesii* *P. strobiformis* *P. ponderosa*	*M. virescens* *Lupinus* spp. *P. fendleriana* *Senecio* spp.	Fitzhugh et al. 1984
Abies concolor / Poa fendleriana H.T. *A. concolor-Pseudotsuga menziesii / P. fendleriana* H.T.]	White Mountains, Arizona	Warm dry	Co-climax with *P. menziesii*	*P. menziesii* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*P. fendleriana* *Fragaria vesca* *Senecio wootonii* *Geranium richardsonii* *Erigeron* spp.	Moir and Ludwig 1979
Abies concolor / Carex foenea H.T.	Pinaleno Mountains, Arizona	Warm dry	Climax	*P. menziesii* *P. ponderosa* *P. strobiformis*	*C. foenea*	Moir and Ludwig 1979
Abies concolor / Erigeron eximius H.T. *A. concolor-Pseudotsuga menziesii / E. superbus* H.T.]	Mountains of northern New Mexico and Arizona	Cool moist	Co-climax with *P. menziesii*	*P. menziesii* *P. ponderosa* *P. tremuloides* *P. pungens* *P. engelmannii* *P. strobiformis*	*E. superbus* (*E. eximius*) *C. foenea* *Lathyrus arizonicus* *Prunus virginiana*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979

Table A3.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *A. concolor*	Principal tree associates	Principal understory species	Authority
Abies concolor / Lathyrus arizonicus H.T. [*A. concolor-Pseudotsuga menziesii / L. arizonicus* H.T.]	San Francisco Peaks, Arizona	Cool dry	Co-climax with *P. menziesii*	*P. menziesii* *P. ponderosa* *P. tremuloides*	*L. arizonicus* *G. richardsonii*	Moir and Ludwi 1979
Abies concolor / Osmorhiza chilensis H.T.	Wasatch Mountains, Utah	Warm moist	Climax	*P. menziesii* *P. tremuloides* *P. engelmannii* *A. grandis*	*O. chilensis* *P. malvaceus* *P. myrsinites* *P. virginiana*	Mauk and Hend son 1984
Abies concolor / Scree H.T.	Mountains of southwestern New Mexico	Cool dry	Co-climax with *P. menziesii*	*P. menziesii* *P. strobiformis*	*Bromus ciliatus* *Jamesia americana* *Koeleria cristata*	DeVelice et al. 1984 Fitzhugh et al. 1984
Abies concolor / Sparse H.T. [*A. concolor-Pseudotsuga menziesii* H.T.]	Mountains of New Mexico, Arizona, and southern Colorado	Warm dry	Co-climax with *P. menziesii*	*P. menziesii* *P. tremuloides* *P. pungens* *P. ponderosa* *P. strobiformis*	*S. oreophilus* *R. neomexicana* *Q. gambelii* *B. repens*	Alexander et al. 1984a DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
***Pseudotsuga menziesii* series**						
Pseudotsuga menziesii / Quercus gambelii H.T.	Mountains of northern Arizona	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. strobiformis* *P. ponderosa*	*Q. gambelii* *B. repens* *R. neomexicana* *S. oreophilus*	Alexander et al. 1984b
Pseudotsuga menziesii / Quercus hypoleucoides H.T.	Mountains of north and central Arizona	Warm dry	Minor climax to *P. menziesii*	*P. menziesii* *P. strobiformis* *P. ponderosa*	*Q. hypoleucoides* *Quercus rugosa* *Muhlenbergia longiligula*	Moir and Ludwig 1979
Pseudotsuga menziesii / Muhlenbergia virescens H.T. [*P. menziesii-Pinus strobiformis / M. virescens* H.T.]	Mountains of northern Arizona and New Mexico	Warm dry	Minor climax to *P. menziesii* *P. strobiformis*. *P. ponderosa* may be fire climax	*P. menziesii* *P. strobiformis* *P. ponderosa* *P. tremuloides* *P. pungens*	*M. virescens* *B. ciliatus* *Pteridium aquilinum* *Pseudocymopterus montanus* *G. richardsonii*	Fitzhugh et al. 1984 Moir and Ludwig 1979
Pseudotsuga menziesii / Holodiscus dumosus H.T. (Scree Forest) [*P. menziesii / Physocarpus monogynus* H.T.]	Mountains of New Mexico	Warm well-drained	Minor climax to *P. menziesii*	*P. menziesii* *P. pungens* *P. tremuloides*	*H. dumosus* *P. monogynus* *B. repens* *P. pratensis*	Moir and Ludwig 1979
Pseudotsuga menziesii / Sparse H.T.	Mountains of northern Arizona	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *P. strobiformis*	*B. repens* *B. richardsonii* *P. fendleriana*	Alexander et al. 1984b
***Picea pungens* series**						
Picea pungens / Arctostaphylos uva-ursi H.T. [*P. pungens-Pseudotsuga menziesii / A. uva-ursi* H.T.]	Mountains of northern New Mexico and southern Colorado	Warm dry	Co-climax with *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *P. ponderosa* *P. tremuloides* *P. flexilis*	*A. uva-ursi* *J. communis* *F. arizonica* *Fragaria ovalis*	DeVelice et al. 1984 Moir and Ludwig 1979

able A3.—(continued)

labitat type, ommunity type, or lant community	Location	Site	Successional status of *A. concolor*	Principal tree associates	Principal understory species	Authority
cea pungens / Linnaea borealis H.T. . *pungens-Pseudotsuga menziesii / L. borealis* H.T.]	Mountains of southern Colorado and northern New Mexico	Cool well-drained	Co-climax with or minor climax to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *P. tremuloides* *P. flexilis* *A. lasiocarpa* *P. engelmannii*	*L. borealis* *P. myrsinites* *V. myrtillus* *R. parviflorus*	DeVelice et al. 1984 Moir and Ludwig 1979
cea pungens / Festuca arizonica H.T.	Jemez Mountains, New Mexico; San Juan Mountains, Colorado	Warm dry	Minor climax to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *P. ponderosa* *P. tremuloides*	*F. arizonica* *C. foenea* *Erigeron* spp. *Fragaria* spp.	DeVelice et al. 1984
cea pungens / Poa pratensis H.T.	Mountains of New Mexico	Warm to cool moist	Minor climax to *P. pungens*	*P. pungens* *P. menziesii* *P. ponderosa* *P. tremuloides* *P. strobiformis*	*P. pratensis* *E. superbus* (*E. eximius*) *G. richardsonii* *Fragaria virginiana*	Fitzhugh et al. 1984 Moir and Ludwig 1979
cea pungens / Carex foenea H.T.	White Mountains and Kaibab Plateau, Arizona; Jemez Mountains, New Mexico	Warm to cool moist	Minor climax to *P. pungens* *P. ponderosa* *P. menziesii*	*P. pungens* *P. ponderosa* *P. menziesii* *P. tremuloides* *P. strobiformis*	*C. foenea* *F. arizonica* *Muhlenbergia montana* *B. ciliatus* *Fragaria* spp.	DeVelice et al. 1984 Moir and Ludwig 1979
cea pungens / Erigeron eximius H.T. . *pungens-Picea engelmannii / E. superbus* H.T.]	Mountains of Arizona, northern New Mexico, and southern Colorado	Cool dry	Co-climax with *P. pungens* *P. menziesii* *P. engelmannii*	*P. pungens* *P. menziesii* *P. flexilis* *P. tremuloides* *P. engelmannii* *A. lasiocarpa* *P. strobiformis* *P. ponderosa*	*E. superbus* (*E. eximius*) *C. foenea* *G. richardsonii* *Thalictrum fendleri* *F. arizonica* *F. virginiana*	DeVelice et al. 1984 Moir and Ludwig 1979
cea pungens / Fragaria ovalis H.T. . *pungens-Pseudotsuga menziesii / Valeriana acutiloba* H.T.]	Mountains of New Mexico and eastern Arizona	Cool moist	Co-climax with *P. pungens* *P. menziesii*	*P. pungens* *P. engelmannii* *P. menziesii* *P. strobiformis* *P. ponderosa* *P. tremuloides* *A. lasiocarpa*	*F. ovalis* *V. acutiloba* *P. pratensis* *Erodium circutarium* *Artemisia dracunculoides*	Alexander et al. 1984a Fitzhugh et al. 1984 Moir and Ludwig 1979
cea pungens / Senecio cardamine H.T. . *pungens-Picea engelmannii / S. cardamine* H.T.]	White Mountains, Arizona	Cool moist	Seral to *P. pungens* *P. engelmannii* *A. lasiocarpa*	*P. pungens* *P. engelmannii* *A. lasiocarpa* *P. ponderosa* *P. menziesii* *P. tremuloides* *P. strobiformis*	*S. cardamine* *P. aquilinum* *Helenium hoopesii* *Viola canadensis*	Moir and Ludwig 1979
Populus tremuloides series and other _P. tremuloides_ dominated vegetation						
opulus tremuloides / Symphoricarpos oreophilus C.T.	Mountains of northern Utah	Warm well-drained	Ultimate climax unknown	*P. tremuloides*	*S. oreophilus* *P. virginiana* *B. repens*	Mauk and Henderson 1984
Picea engelmanii series						
icea engelmannii / Senecio cardamine H.T.	Blue Mountains, Arizona	Cool moist	Seral to *P. engelmannii*	*P. engelmannii* *P. menziesii* *A. lasiocarpa* *P. pungens* *P. strobiformis* *P. ponderosa* *P. tremuloides*	*S. cardamine* *F. ovalis* *G. richardsonnii* *V. canadensis*	Fitzhugh et al. 1984

Table A3.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *A. concolor*	Principal tree associates	Principal understory species	Authority
			***Abies lasiocarpa* series**			
Abies lasiocarpa / Acer glabrum H.T.	Mountains of central and southern Utah	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. pungens* *P. menziesii* *P. flexilis*	*A. glabrum* *A. alnifolia* *B. repens* *S. oreophilus* *T. fendleri* *O. chilensis*	Youngblood 1984
Abies lasiocarpa / Berberis repens H.T.	Mountains of Utah	Warm-cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* (minor climax) *P. contorta* *P. pungens* *P. menziesii* *P. flexilis* *P. tremuloides*	*B. repens* *Ribes montigenum* *Carex geyeri* *P. myrsinites* *S. oreophilus* *J. communis*	Mauk and Hende son 1984 Pfister 1972 Youngblood 1984
Abies lasiocarpa / Juniperus communis H.T.	Mountains of southern Utah, northern Arizona, and New Mexico	Warm to cold dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides* *P. pungens* (UT)	*J. communis* *Pyrola secunda* *Arnica cordifolia* *S. oreophilus* *R. woodsii*	Moir and Ludwig 1979 Youngblood 1984
Abies lasiocarpa / Physocarpus malvaceus H.T.	Mountains of northern Utah	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides* *A. grandis*	*P. malvaceus* *B. repens* *A. alnifolia* *S. oreophilus* *P. myrsinites*	Mauk and Hende son 1984
Abies lasiocarpa / Rubus parviflorus H.T.	Mogollon Mountains, New Mexico	Warm moist	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides*	*R. parviflorus* *V. myrtillus* *A. glabrum* *P. myrsinites*	Moir and Ludwig 1979
Abies lasiocarpa / Vaccinium myrtillus H.T. [*A. lasiocarpa / V. myrtillus-Linnaea borealis* H.T.] [*A. lasiocarpa / V. myrtillus-Rubus parviflorus* H.T.] [*A. lasiocarpa / Vaccinium scoparium-L. borealis* H.T.]	Mogollon Plateau, Arizona; mountains of northern New Mexico and southern Colorado	Cool moist to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *Pinus aristata* *P. tremuloides* *P. menziesii* *P. flexilis* *P. strobiformis* *P. pungens*	*V. myrtillus* *Disporum trachycarpum* *Polemonium flavum* *V. scoparium* *P. myrsinites* *A. cordifolia* *R. parviflorus* *L. borealis*	DeVelice et al. 1984 Moir and Ludwig 1979
Abies lasiocarpa / Aconitum columbianum H.T.	Mountains of central and southern Utah	Cool moist	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides*	*A. columbianum* *Actaea rubra* *A. cordifolia* *B. ciliatus*	Youngblood 1984
Abies lasiocarpa / Erigeron eximius H.T. [*A. lasiocarpa / E. superbus* H.T.]	Mountains of southwestern Colorado, northern New Mexico, and Arizona	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*E. superbus* (*E. eximius*) *G. richardsonii* *L. arizonicus* *Lonicera involucrata* *A. cordifolia*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979

Table A4.—Habitat types, community types, and plant communities in which *Picea pungens* is climax, co-climax, minor climax, or seral.

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. pungens***	**Principal tree associates**	**Principal understory species**	**Authority**
			***Picea pungens* series**			
Picea pungens / *Amelanchier alnifolia* H.T.	Mountains of western and central Colorado	Warm moist	Climax	*Abies lasiocarpa* *Pseudotsuga menziesii* *Populus angustifolia*	*A. alnifolia* *Cornus stolonifera* *Carex geyeri* *Swida sericea*	Hess and Wasser 1982 Komarkova 1984
Picea pungens / *Arctostaphylos uva-ursi* H.T. [*P. pungens*-*Pseudotsuga menziesii* / *A. uva-ursi* H.T.]	Mountains of northern New Mexico and southern Colorado	Warm dry	Co-climax with *P. menziesii* *A. concolor*	*Abies concolor* *P. menziesii* *Pinus ponderosa* *Populus tremuloides* *Pinus flexilis*	*A. uva-ursi* *Juniperus communis* *Festuca arizonica* *Fragaria ovalis*	DeVelice et al. 1984 Moir and Ludwig 1979
Picea pungens / *Berberis repens* H.T.	Mountains of Utah	Cool dry	Climax	*P. menziesii* (minor climax) *P. tremuloides* *Pinus contorta* *P. ponderosa* *Juniperus scopulorum* *P. flexilis*	*B. repens* *J. communis* *Pachistima myrsinites* *Aquilegia coerulea* *Pyrola secunda* *Ribes montigenum* *Symphoricarpos oreophilus*	Mauk and Henderson 1984 Pfister 1972 Youngblood 1984
Picea pungens / *Cornus stolonifera* H.T.	Mountains of north-central and northwestern New Mexico	Warm moist	Co-climax with *P. menziesii*	*P. menziesii* *P. tremuloides* *Juniperus* spp.	*C. stolonifera* *B. repens* *P. myrsinites* *Carex foenea*	Alexander et al. 1984c
Picea pungens / *Juniperus communis* H.T.	Mountains of central Utah	Cool dry	Climax	*P. menziesii* *P. tremuloides* *P. ponderosa* *P. flexilis* *J. scopulorum*	*J. communis* *A. uva-ursi* *S. oreophilus* *B. repens* *P. myrsinites*	Youngblood 1984
Picea pungens / *Linnaea borealis* H.T. [*P. pungens*-*Pseudotsuga menziesii* / *L. borealis* H.T.]	Mountains of southern Colorado and northern New Mexico	Cool well-drained	Co-climax with *P. menziesii* *A. concolor*	*P. menziesii* *A. concolor* *P. tremuloides* *P. flexilis* *A. lasiocarpa* *Picea engelmannii*	*L. borealis* *P. myrsinites* *Vaccinium myrtillus* *Rubus parviflorus*	DeVelice et al. 1984 Moir and Ludwig 1979
Picea pungens / *Agropyron spicatum* H.T.	Uinta Mountains, Utah	Warm dry	Climax	*P. menziesii* *P. tremuloides* *P. contorta* *P. ponderosa* *P. flexilis* *J. scopulorum*	*A. spicatum* *B. repens* *J. communis* *P. myrsinites*	Mauk and Henderson 1984
Picea pungens / *Festuca arizonica* H.T.	Mountains of northern New Mexico, and southern and western Colorado	Warm dry	Co-climax with *P. menziesii*	*P. menziesii* *A. concolor* *P. ponderosa* *P. tremuloides*	*F. arizonica* *C. foenea* *Erigeron* spp. *Fragaria* spp.	DeVelice et al. 1984 Komarkova 1984
Picea pungens / *Poa pratensis* H.T.	Mountains of New Mexico	Warm to cool moist	Climax	*P. menziesii* *P. ponderosa* *P. tremuloides* *A. concolor* *Pinus strobiformis*	*P. pratensis* *E. superbus* (*E. eximius*) *Geranium richardsonii* *Fragaria virginiana*	Fitzhugh et al. 1984 Moir and Ludwig 1979
Picea pungens / *Poa* spp. H.T.	Mountains of north-central Colorado	Warm moist	Climax	Usually pure stands. May contain *P. menziesii* *P. tremuloides*	*Poa* spp. *A. alnifolia* *Rosa* spp. *Salix* spp.	Hoffman and Alexander 1983

Table A4.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. pungens*	Principal tree associates	Principal understory species	Authority
Picea pungens / Carex foenea H.T.	White Mountains and Kaibab Plateau, Arizona; mountains of northern New Mexico	Warm to cool moist	Co-climax with *P. menziesii*	*P. menziesii* *P. ponderosa* *A. concolor* *P. tremuloides* *P. strobiformis* *P. engelmannii*	*C. foenea* *F. arizonica* *Muhlenbergia montana* *Bromus ciliatus* *Fragaria* spp. *Festuca* spp. *B. repens*	Alexander et al. 1984c DeVelice et al. 1984 Moir and Ludwi 1979
Picea pungens / Arnica cordifolia H.T.	Front Range, north-central Colorado	Cool moist	Climax	*P. menziesii* *P. tremuloides*	*A. cordifolia* *Smilacina stellata* *J. communis* *Calamagrostis canadensis*	Hess 1981
Picea pungens / Equisetum arvense H.T.	Mountains of southern Utah	Warm to cool wet	Climax	*P. engelmannii* *P. tremuloides* *P. menziesii*	*E. arvense* *G. richardsonii* *Thalictrum fendleri* *Osmorhiza chilensis*	Youngblood 198
Picea pungens / Erigeron eximius H.T. [*P. pungens-Picea engelmannii / E. superbus* H.T.]	Mountains of northern New Mexico and southern Colorado	Cool dry	Co-climax with *A. concolor* *P. menziesii* *P. engelmannii*	*A. concolor* *P. menziesii* *P. engelmannii* *P. flexilis* *P. tremuloides* *A. lasiocarpa* *P. ponderosa* *P. strobiformis*	*E. superbus* (*E. eximius)* *C. foenea* *G. richardsonii* *T. fendleri* *F. arizonica* *F. virginiana*	DeVelice et al. 1984 Moir and Ludwi 1979
Picea pungens / Fragaria ovalis H.T. [*P. pungens-Pseudotsuga menziesii / Valeriana acutiloba* H.T.]	Mountains of New Mexico and eastern Arizona	Cool moist	Co-climax with *P. menziesii*	*P. menziesii* *A. concolor* *P. strobiformis* *P. ponderosa* *P. tremuloides* *P. engelmannii* *A. lasiocarpa*	*F. ovalis* *V. acutiloba* *C. foenea* *F. arizonica* *Erodium circutarium* *E. superbus* (*E. eximius)* *Artemisia dracunculoides*	Alexander et al. 1984a Fitzhugh et al. 1984 Moir and Ludwig 1979
Picea pungens / Senecio cardamine H.T. [*P. pungens-Picea engelmannii / S. caradamine* H.T.]	White Mountains, Arizona	Cool moist	Co-climax with *P. engelmannii* *A. lasiocarpa*	*P. engelmannii* *A. lasiocarpa* *A. concolor* *P. ponderosa* *P. menziesii* *P. tremuloides* *P. strobiformis*	*S. cardamine* *Pteridium aquilinum* *Helenium hoopesii* *Viola canadensis*	Moir and Ludwig 1979
			***Pseudotsuga menziesii* series**			
Pseudotsuga menziesii / Muhlenbergia virescens H.T.	Mountains of southwestern New Mexico	Warm dry	Minor climax to *P. menziesii* *P. ponderosa*	*P. menziesii* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*M. virescens* *Quercus gambelii*	Fitzhugh et al. 1984
Pseudotsuga menziesii / Holodiscus dumosus H.T. (Scree Forests) [*P. menziesii / Physocarpus monogynus* H.T.]	Mountains of New Mexico	Warm well-drained	Minor climax to *P. menziesii*	*P. menziesii* *P. tremuloides* *A. concolor*	*H. dumosus* *P. monogynus* *B. repens* *P. pratensis*	Moir and Ludwig 1979
			***Abies concolor* series**			
Abies concolor / Acer glabrum H.T.	Mountains of northern Arizona, New Mexico, and southern Colorado	Warm moist to well-drained	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. engelmannii* *P. tremuloides*	*A. glabrum* *A. alnifolia* *B. repens* *P. myrsinites*	DeVelice et al. 1984

able A4.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. pungens*	Principal tree associates	Principal understory species	Authority
bies concolor / Arctostaphylos patula H.T.	Mountains of southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. flexilis* *P. ponderosa* *J. scopulorum*	*A. patula* *S. oreophilus* *J. communis* *B. repens*	Youngblood 1984
bies concolor / Berberis repens H.T.	Mountains of central and southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. ponderosa* *P. tremuloides* *P. flexilis*	*B. repens* *J. communis* *S. oreophilus* *Rosa woodsii* *P. myrsinites*	Youngblood 1984
bies concolor / Juniperus communis H.T.	Mountains of Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. tremuloides* *P. flexilis*	*J. communis* *S. oreophilus* *R. woodsii* *B. repens* *Carex rossii*	Youngblood 1984
bies concolor / Vaccinium myrtillus H.T.	Mountains of northern New Mexico and southern Colorado	Cool dry	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*V. myrtillus* *A. glabrum* *A. uva-ursi* *P. myrsinites* *R. parviflorus*	DeVelice et al. 1984
bies concolor / Erigeron eximius H.T.	Mountains of northern New Mexico	Cool moist	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. engelmannii* *P. tremuloides* *P. ponderosa*	*E. eximius* (*E. superbus*) *C. foenea* *Lathyrus* spp. *Fragaria* spp.	DeVelice et al. 1984
bies concolor / Sparse H.T. *. concolor-Pseudotsuga menziesii* H.T.]	Mountains of northern New Mexico and southern Colorado	Warm dry	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. tremuloides* *P. ponderosa* *P. strobiformis*	*S. oreophilus* *Q. gambelii* *B. repens* *Robinia neomexicana*	DeVelice et al. 1984 Moir and Ludwig 1979
			***Picea engelmannii* series**			
icea engelmannii / Carex disperma H.T.	Mountains of northwestern Wyoming eastern and central Idaho	Cool moist	Occasional co-climax with *P. engelmannii*	*P. engelmannii* *A. lasiocarpa*	*C. disperma*	Steele et al. 1983
icea engelmannii / Equisetum arvense H.T.	Mountains of northwestern Wyoming and eastern Idaho	Warm to cool wet	Occasional co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *A. lasiocarpa*	*E. arvense* *Streptopus amplexifolius* *Senecio triangularis* *Luzula parviflora*	Steele et al. 1983
icea engelmannii / Galium triflorum H.T.	Mountains of northwestern Wyoming	Cool moist	Occasional co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. menziesii* *A. lasiocarpa*	*G. triflorum* *Actaea rubra* *S. stellata*	Steele et al. 1983
icea engelmannii / Senecio cardamine H.T.	Blue Mountains, Arizona	Cool moist	Seral to *P. engelmannii*	*P. engelmannii* *P. menziesii* *A. lasiocarpa* *A. concolor* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*S. cardamine* *F. ovalis* *G. richardsonii* *V. canadensis*	Fitzhugh et al. 1984

Table A4.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. pungens*	Principal tree associates	Principal understory species	Authority
			Abies lasiocarpa series			
Abies lasiocarpa / *Acer glabrum* H.T.	Mountains of central and southern Utah	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *A. concolor* *P. menziesii* *P. engelmannii* *P. flexilis* *P. tremuloides*	*A. glabrum* *A. alnifolia* *B. repens* *S. oreophilus* *O. chilensis* *T. fendleri*	Youngblood 198
Abies lasiocarpa / *Berberis repens* H.T.	Mountains of Utah	Warm to cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. menziesii* *A. concolor* *P. flexilis* *P. tremuloides*	*B. repens* *R. montigenum* *J. communis* *C. geyeri* *S. oreophilus* *R. woodsii* *P. myrsinites*	Mauk and Hend son 1984 Youngblood 198
Abies lasiocarpa / *Juniperus communis* H.T.	Mountains of southern Utah	Warm to cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *P. menziesii* *P. ponderosa* *A. concolor*	*J. communis* *R. woodsii* *S. oreophilus* *B. repens*	Youngblood 198
Abies lasiocarpa / *Vaccinium myrtillus* H.T. [*A. lasiocarpa* / *V. myrtillus*-*Linnaea borealis* H.T.] [*A. lasiocarpa* / *Vaccinium scoparium*-*L. borealis* H.T.]	Mountains of northern New Mexico and southern Colorado	Cool moist to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *A. concolor* *P. tremuloides* *P. menziesii*	*V. myrtillus* *V. scoparium* *L. borealis* *E. superbus* (*E. eximius*) *F. virginiana* *P. myrsinites* *V. canadensis*	DeVelice et al. 1984 Moir and Ludwi 1979
Abies lasiocarpa / *Calamagrostis canadensis* H.T.	Mountains of northern Utah	Warm wet	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. tremuloides*	*C. canadensis* *L. borealis* *E. arvense* *G. triflorum*	Mauk and Hend son 1984
Abies lasiocarpa / *Actaea rubra* H.T.	Mountains of northwestern Wyoming and southern Idaho	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta*	*A. rubra* *Lonicera utahensis* *Vaccinium globulare* *A. glabrum*	Steele et al. 198
Abies lasiocarpa / *Erigeron eximius* H.T. [*A. lasiocarpa* / *E. superbus* H.T.]	Mountains of Arizona, New Mexico, and southern Colorado	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *A. concolor* *P. tremuloides* *P. menziesii* *P. strobiformis*	*E. superbus* (*E. eximius*) *B. ciliatus* *F. virginiana* *Lonicera involucrata* *A. cordifolia*	DeVelice et al. 1984 Moir and Ludwig 1979
			Riparian series			
Alnus tenuifolia / *Equisetum arvense* H.T.	Streambanks, montane zone, north-central Colorado	Warm moist to wet	Minor climax to *A. tenuifolia*	*A. tenuifolia* *Betula occidentalis* *P. tremuloides*	*E. arvense* *Salix* spp. *R. woodsii* *A. glabrum*	Hess 1981
Populus angustifolia / *Salix exigua* H.T.	Streambanks, montane zone, north-central Colorado	Warm moist to wet	Minor climax to *P. angustifolia*	*P. angustifolia* *P. tremuloides* *J. scopulorum*	*Salix* spp. *A. glabrum*	Hess 1981

Table A5.—Habitat types, community types, and plant communities in which *Populus tremuloides* is a major climax, co-climax, minor climax, or seral.

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. tremuloides*	Principal tree associates	Principal understory species	Authority
			***Populus tremuloides* series and other *P. tremuloides* dominated vegetation**			
pulus tremuloides-Pseudotsuga menziesii / Amelanchier alnifolia C.T. ID) *tremuloides / A. alnifolia* C.T. (ID); H.T. CO) *tremuloides / A. alnifolia-Prunus virgi- iana* P.C. (CO)	Mountains of southeastern Idaho and western Colorado	Warm dry	Climax (CO); seral to *P. menziesii* or unknown ultimate climax (ID)	*P. menziesii* (ID) may occur in pure stands (CO)	*A. alnifolia* *P. virginiana* *Pachistima myrsinites* *Symphoricarpos oreophilus* *Spiraea betulifolia* *Calamagrostis rubescens*	Komarkova 1984 Mueggler and Campbell 1982
pulus tremuloides / Artemisia tridentata C.T.	Mountains of southeastern Idaho and western Wyoming	Warm dry	Climax or seral to unknown ultimate climax	Usually pure stands	*A. tridentata* *Bromus carinatus* *S. oreophilus* *Melica spectabilis* *Purshia tridentata* *Festuca idahoensis*	Mueggler and Campbell 1982 Youngblood and Mueggler 1981
pulus tremuloides-Abies lasiocarpa / Berberis repens C.T. *tremuloides / B. repens* C.T.	Mountains of western Wyoming	Warm to cool. Well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *Picea engelmannii* *Pinus contorta* *Pinus flexilis*	*B. repens* *Symphoricarpos albus* *P. myrsinites*	Youngblood and Mueggler 1981
pulus tremuloides-Corylus cornuta H.T.	Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Warm well-drained	Climax or seral to unknown ultimate climax	*Betula papyrifera*	*C. cornuta* *Aralia nudicaulis* *Aster ciliolatus* *Osmorhiza chilensis* *Pteridium aquilinum*	Hoffman 1984
pulus tremuloides / Juniperus communis H.T. (UT); C.T. (WY)	Mountains of western Wyoming; Uinta Mountains, Utah	Warm dry	Climax or seral to unknown ultimate climax	Usually pure stands. May contain *P. flexilis* *P. contorta*	*J. communis* *B. repens* *Shepherdia canadensis* *Rosa woodsii*	Mauk and Henderson 1984 Youngblood and Mueggler 1981
pulus tremuloides / Pachistima myrsinites C.T. (ID); P.C. (CO)	Mountains of southeastern Idaho, central and southwestern Colorado	Warm dry	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii* *P. menziesii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta* may be pure stands (ID)	*P. myrsinites* *Vaccinium scoparium* *Carex geyeri* *C. rubescens* *Geranium viscosissimum*	Mueggler and Campbell 1982 Steen and Dix 1974
pulus tremuloides-Abies lasiocarpa / Prunus virginiana C.T., *tremuloides / P. virginiana* C.T.	Mountains of western Wyoming	Warm dry	Seral to either *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. contorta*	*P. virginiana* *B. repens* *S. oreophilus* *R. woodsii*	Youngblood and Mueggler 1981
pulus tremuloides-Abies lasiocarpa / Shepherdia canadensis C.T., *tremuloides / S. canadensis* C.T.	Mountains of western Wyoming	Cool-dry to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. engelmannii* *P. flexilis*	*S. canadensis* *G. viscosissimum* *Arnica cordifolia* *R. woodsii* *Thalictrum fendleri*	Youngblood and Mueggler 1981
pulus tremuloides-Pseudotsuga menziesii / Spiraea betulifolia C.T., *tremuloides / S. betulifolia* C.T.	Mountains of southeastern Idaho and western Wyoming	Warm dry	Seral to *P. menziesii*	*P. menziesii*	*S. betulifolia* *A. alnifolia* *B. repens* *C. rubescens*	Mueggler and Campbell 1982 Youngblood and Mueggler 1981

Table A5.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. tremuloides***	**Principal tree associates**	**Principal understory species**	**Authority**
Populus tremuloides-Abies lasiocarpa / Symphoricarpos oreophilus C.T., *P. tremuloides / S. oreophilus* H.T. (CO); C.T. (WY,ID,UT)	Mountains of southeastern Idaho, northern Utah, western Wyoming, northern, western and central Colorado	Warm well-drained	Climax or seral to unknown ultimate climax. Probably *A. lasiocarpa*	*A. lasiocarpa* *Abies concolor* *P. menziesii* may be pure stands (CO)	*S. oreophilus* *P. virginiana* *B. repens* *Elymus glaucus* *G. viscosissimum* *Lupinus argenteus* *Rudbeckia occidentalis* *Poa pratensis* *C. rubescens* *C. geyeri* *A. alnifolia*	Hess and Wass 1982 Hoffmann and Alexander 19 1983 Komarkova 198 Mauk and Hen son 1984 Mueggler and Campbell 198 Steele et al. 19 Youngblood an Mueggler 198
Populus tremuloides-Pseudotsuga menziesii / Symphoricarpos oreophilus C.T., *P. tremuloides / S. oreophilus* C.T.	Mountains of southeastern Idaho	Warm dry	Seral to *P. menziesii*	*P. menziesii* *A. lasiocarpa* *P. contorta*	*S. oreophilus* *C. rubescens* *P. pratensis* *R. occidentalis* *C. geyeri*	Mueggler and Campbell 198
Populus tremuloides / Wyethia amplexicaulis C.T.	Mountains of southeastern Idaho and western Wyoming	Cool well-drained	Climax or seral to unknown ultimate climax	Usually pure stands	*W. amplexicaulis* *R. occidentalis*	Mueggler and Campbell 198 Youngblood and Mueggler 198
Populus tremuloides-Pinus contorta / Calamagrostis rubescens C.T., *P. tremuloides / C. rubescens* C.T.	Mountains of southeastern Idaho	Warm dry	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. contorta*	*C. rubescens* *S. oreophilus* *P. myrsinites* *L. argenteus* *T. fendleri* *G. viscosissimum*	Mueggler and Campbell 198
Populus tremuloides-Pseudotsuga menziesii / Calamagrostis rubescens C.T., *P. tremuloides / C. rubescens* C.T.	Mountains of southeastern Idaho and western Wyoming	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. contorta* may be pure stands	*C. rubescens* *S. oreophilus* *T. fendleri* *A. cordifolia* *L. argenteus*	Mueggler and Campbell 198 Youngblood and Mueggler 198
Populus tremuloides / Elymus glaucus P.C.	Mountains of central and southwestern Colorado	Warm moist to well-drained	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta*	*E. glaucus* *A. alnifolia* *Symphoricarpos* spp. *Ligusticum porteri*	Steen and Dix 1
Populus tremuloides / Festuca thurberi H.T. P.C.	Mountains of Colorado	Warm dry	Climax or seral to unknown ultimate climax	Usually pure stands but may contain *P. contorta* *P. engelmannii* *A. lasiocarpa* *P. menziesii*	*F. thurberi* *B. repens* *S. oreophilus* *Fragaria ovalis*	Hess 1981 Hess and Wasse 1982 Komarkova 1984 Steen and Dix 1
Populus tremuloides / Poa pratensis C.T.	Mountains of southeastern Idaho	Warm dry	Seral to unknown ultimate climax	*P. menziesii* *A. lasiocarpa* may be pure stands	*P. pratensis* *P. nervosa* *Physocarpus monogynous* *Smilacina stellata* *C. rubescens* *T. fendleri*	Mueggler and Campbell 1982

able A5.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. tremuloides*	Principal tree associates	Principal understory species	Authority
opulus tremuloides / Carex geyeri H.T.	Uinta Mountains, Utah; mountains of southern Wyoming and north-central Colorado	Warm to cool. Dry to well-drained	Climax	Usually pure stands	*G. geyeri* *J. communis* *A. cordifolia* *Lathyrus leucanthus*	Hess 1981 Hoffman and Alexander 1983 Mauk and Henderson 1984 Wirsing and Alexander 1975
opulus tremuloides-Abies lasiocarpa / Arnica cordifolia C.T., *tremuloides / A. cordifolia* C.T.	Mountains of western Wyoming	Cool moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta*	*A. cordifolia* *S. oreophilus* *Carex rossii* *O. chilensis* *Poa nervosa*	Youngblood and Mueggler 1981
opulus tremuloides / Astragalus miser C.T.	Mountains of western Wyoming	Warm dry	Climax or seral to unknown ultimate climax	*P. flexilis*	*A. miser* *L. argenteus* *G. viscosissimum*	Youngblood and Mueggler 1981
opulus tremuloides / Equisetum arvense C.T.	Mountains of western Wyoming	Cool wet	Seral to *P. engelmannii A. lasiocarpa*	*P. engelmannii* *A. lasiocarpa* *P. contorta*	*E. arvense* *E. glaucus* *T. fendleri*	Youngblood and Mueggler 1981
opulus tremuloides / Geranium viscosissimum C.T.	Mountains of southeastern Idaho	Warm dry	Climax or seral to *A. lasiocarpa*	*A. lasiocarpa* may be pure stands	*G. viscosissimum* *Symphoricarpos* spp. *L. argenteus* *T. fendleri*	Mueggler and Campbell 1982
opulus tremuloides / Heracleum lanatum H.T. (CO); C.T. (WY) *opulus tremuloides / Heracleum sphondyllium* H.T.]	Mountains of western Wyoming, northwestern and north-central Colorado	Warm moist	Climax (CO) or seral to *A. lasiocarpa* (WY)	*A. lasiocarpa* *P. engelmannii* *P. contorta* usually pure stands (CO)	*H. lanatum* *H. sphondyllium* *Pedicularis bracteosa* *T. fendleri* *E. glaucus* *Bromus ciliatus*	Hess and Wasser 1982 Hoffman and Alexander 1980, 1983 Youngblood and Mueggler 1981
opulus tremuloides-Abies lasiocarpa / Ligusticum filicinum C.T. *tremuloides / L. filicinum* C.T.	Mountains of western Wyoming	Cool moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii*	*L. filicinum* *T. fendleri* *G. viscosissimum* *Osmorhiza occidentalis*	Youngblood and Mueggler 1981
opulus tremuloides / Lupinus argenteus H.T.	Bighorn Mountains, Wyoming	Warm well-drained	Climax	Usually pure stands	*Lupinus* spp. *Carex* spp. *Trifolium* spp.	Hoffman and Alexander 1976
opulus tremuloides-Abies lasiocarpa / Pedicularis racemosa C.T.	Mountains of western Wyoming	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii*	*P. racemosa* *A. cordifolia* *S. oreophilus*	Youngblood and Mueggler 1981
opulus tremuloides / Pteridium aquilinum H.T. (CO)	Mountains of western and north-central Colorado	Warm poorly-drained	Climax	Usually pure stands	*P. aquilinum* *T. fendleri* *E. glaucus* *C. geyeri* *Melica subulata*	Hoffman and Alexander 1980, 1983 Komarkova 1984
pulus tremuloides / Ranunculus alismaefolius C.T.	Mountains of western Wyoming	Cool moist to wet	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii*	*R. alismaefolius* *Carex microptera* *Trifolium longipes*	Youngblood and Mueggler 1981
pulus tremuloides-Abies lasiocarpa / Rudbeckia occidentalis C.T., *tremuloides / R. occidentalis* C.T.	Mountains of southeastern Idaho and western Wyoming	Cool moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii*	*R. occidentalis* *T. longipes* *Nemophila brevifolia* *M. spectabilis* *Symphoricarpos* spp.	Mueggler and Campbell 1982 Youngblood and Mueggler 1981

Table A5.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. tremuloides***	**Principal tree associates**	**Principal understory species**	**Authority**
Populus tremuloides-Abies lasiocarpa / Thalictrum fendleri C.T. (ID), *P. tremuloides / T. fendleri* H.T. (CO); C.T. (WY)	Mountains of southeastern Idaho; western Wyoming, and Colorado	Warm moist to well-drained	Climax (CO) *P. menziesii* ultimate climax (WY). Seral to *A. lasiocarpa* (ID)	*A. lasiocarpa* *P. menziesii* *P. flexilis* may be pure stands (CO)	*T. fendleri* *C. geyeri* *E. glaucus* *S. oreophilus* *G. viscosissimum*	Hess 1981 Hess and Wass 1982 Hoffman and Al ander 1980, 19 Komarkova 1984 Mueggler and Campbell 198 Youngblood and Mueggler 198
Populus tremuloides / Veratrum tenuipetalum H.T.	Mountains of northwestern Colorado	Cool wet	Climax	Usually pure stands	*V. tenuipetalum* *Mertensia ciliata* *L. porteri* *B. ciliatus*	Hoffman and Al ander 1980
***Pinus ponderosa* series**						
Pinus ponderosa / Symphoricarpos albus H.T.	Mountains of central Idaho; Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Warm dry to well-drained	Seral to *P. ponderosa*	*P. ponderosa* (not in all stands in SD and WY)	*S. albus* *S. betulifolia* *Rosa* spp. *Juniperus communis* *Balsamorhiza sagittata* *Oryzopsis asperifolia*	Hoffman 1984 Steele et al. 198
Pinus ponderosa / Symphoricarpos oreophilus H.T.	Mountains of central Utah	Warm dry	Seral to *P. ponderosa*	*P. ponderosa* *J. scopulorum*	*S. oreophilus* *B. repens* *C. rossii* *Muhlenbergia montana*	Youngblood 198
Pinus ponderosa / Festuca idahoensis H.T.	Uinta Mountains, Utah	Warm dry	Seral to *P. ponderosa*	*P. ponderosa* *P. contorta* *J. scopulorum*	*F. idahoensis* *Arctostaphylos patula* *A. tridentata*	Mauk and Hend son 1984
Pinus ponderosa / Carex geyeri H.T.	Uinta Mountains, Utah	Warm dry	Seral to *P. ponderosa*	*P. ponderosa* *P. contorta*	*C. geyeri* *A. alnifolia* *B. repens* *P. nervosa*	Mauk and Hend son 1984
***Pinus flexilis* series**						
Pinus flexilis / Arctostaphylos uva-ursi H.T.	Mountains of northern New Mexico and southern Colorado	Warm dry	Seral to *P. flexilis* *P. menziesii*	*P. flexilis* *P. menziesii* *P. engelmannii*	*A. uva-ursi* *J. communis*	DeVelice et al. 1984
Pinus flexilis / Juniperus communis H.T.	Mountains of north-central Colorado	Warm dry	Seral to *P. flexilis*	*P. flexilis* *P. menziesii* *P. ponderosa* *P. contorta*	*J. communis* *C. rossii* *Geranium fremontii*	Hess 1981
Pinus flexilis-Pinus longaeva H.T.	Mountains of central and southern Utah	Warm dry	Seral to *P. flexilis* *P. longaeva*	*P. flexilis* *P. longaeva* *P. menziesii* *J. scopulorum*	*S. oreophilus* *J. communis* *B. repens* *C. rossii* *A. miser*	Youngblood 198

able A5.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. tremuloides*	Principal tree associates	Principal understory species	Authority
			***Pseudotsuga menziesii* series**			
seudotsuga menziesii / *Acer glabrum* H.T.	Mountains of eastern Idaho, northern Utah, and northwestern Wyoming	Cool moist	Seral to *P. menziesii*	*P. menziesii* *P. flexilis* *Juniperus scopulorum* *P. contorta* *Abies grandis* (UT)	*A. glabrum* *S. oreophilus* *A. alnifolia* *P. myrsinites*	Mauk and Henderson 1984 Steele et al. 1981, 1983
seudotsuga menziesii / *Arctostaphylos uva-ursi* H.T.	Mountains of southwestern New Mexico	Warm dry	Seral to *P. menziesii* *P. flexilis*	*P. menziesii* *P. strobiformis* *P. ponderosa* *P. flexilis*	*A. uva-ursi* *J. communis*	Fitzhugh et al. 1984
seudotsuga menziesii / *Berberis repens* H.T.	Mountains of southeastern Idaho, northern Utah, and northwestern Wyoming	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. flexilis* *P. contorta* *P. ponderosa* *J. scopulorum* *A. grandis*	*B. repens* *S. oreophilus* *C. geyeri* *J. communis* *A. cordifolia*	Mauk and Henderson 1984 Steele et al. 1983
seudotsuga menziesii / *Cercocarpus ledifolius* H.T.	Mountains of central and southern Utah	Warm dry	Seral to *P. menziesii*	*P. menziesii* *Pinus edulis* *P. longaeva* *P. ponderosa*	*C. ledifolius* *B. oreophilus* *A. tridentata* *B. repens*	Youngblood 1984
seudotsuga menziesii / *Pachistima myrsinites* H.T.	Mountains of northwestern Colorado	Warm dry	Seral to *P. menziesii*	*P. menziesii*	*P. myrsinites* *S. oreophilus* *A. glabrum* *Quercus gambelii*	Hoffman and Alexander 1983
seudotsuga menziesii / *Physocarpus malvaceus* H.T.	Mountains of central Utah	Cool moist to well-drained	Seral to *P. menziesii*	*P. menziesii* *P. contorta* *J. scopulorum* *A. grandis*	*P. malvaceus* *P. virginiana* *Holodiscus discolor* *S. albus* *P. myrsinites* *B. repens*	Mauk and Henderson 1984 Youngblood 1984
seudotsuga menziesii / *Symphoricarpos albus* H.T.	Mountains of eastern Idaho and northwestern Wyoming	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *P. contorta* *P. flexilis*	*S. albus* *S. betulifolia* *A. uva-ursi* *B. repens*	Steele et al. 1981, 1983
seudotsuga menziesii / *Symphoricarpos oreophilus* H.T.	Mountains of northern and central Utah	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *J. scopulorum* *P. flexilis* *P. contorta*	*S. oreophilus* *Ribes montigenum* *A. tridentata* *Stellaria jamesiana* *B. repens*	Mauk and Henderson 1984 Youngblood 1984
seudotsuga menziesii / *Bromus ciliatus* H.T.	Mountains of north-central and northwestern New Mexico	Warm moist	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *P. strobiformis*	*B. ciliatus* *A. glabrum* *Carex* spp.	Alexander et al. 1984c
seudotsuga menziesii / *Calamagrostis rubescens* H.T.	Mountains of eastern Idaho and northwestern Wyoming	Warm to cool dry to well-drained	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *P. flexilis* *P. contorta*	*C. rubescens* *C. geyeri* *A. cordifolia* *A. uva-ursi* *P. myrsinites*	Steele et al. 1981, 1983
seudotsuga menziesii / *Festuca arizonica* H.T.	Mountains of northern Arizona and New Mexico	Warm dry	Seral to *P. menziesii*	*P. menziesii* *Pinus strobiformis* *P. ponderosa* *P. flexilis*	*F. arizonica* *M. montana* *Koeleria cristata* *Erigeron subtrinervis*	Alexander et al. 1984c DeVelice et al. 1984 Moir and Ludwig 1979

Table A5.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. tremuloides*	Principal tree associates	Principal understory species	Authority
Pseudotsuga menziesii / Muhlenbergia virescens H.T.	Mountains of southwestern New Mexico and Arizona	Warm dry	Seral to *P. menziesii* *P. ponderosa*	*P. menziesii* *P. ponderosa* *Picea pungens* *P. strobiformis*	*M. virescens* *Q. gambelii* *C. rossii* *Poa fendleriana*	Alexander et al. 1984b Fitzhugh et al. 1984
Pseudotsuga menziesii / Holodiscus dumosus H.T. (Scree Forest) [*P. menziesii / Physocarpus monogynus* H.T.]	Mountains of New Mexico	Warm dry to well-drained	Seral to *P. menziesii*	*P. menziesii* *A. lasiocarpa* *P. engelmannii* *P. strobiformis* *A. concolor* *P. pungens*	*H. dumosus* *Salix* spp. *S. oreophilus* *B. ciliatus* *P. monogynus*	Fitzhugh et al. 1984 Moir and Ludwig 1979
Pseudotsuga menziesii / Osmorhiza chilensis H.T.	Mountains of southern Idaho and northern Utah	Warm well-drained	Seral to *P. menziesii*	*P. menziesii* *P. contorta* *A. grandis* *J. scopulorum*	*O. chilensis* *Smilacina racemosa* *Viola nuttallii* *P. virginiana* *A. cordifolia*	Mauk and Hende son 1984 Steele et al. 198
***Abies concolor* series**						
Abies concolor / Acer glabrum H.T. [*A. concolor-Pseudotsuga menziesii / A. glabrum* H.T.]	Mountains of southern Utah, New Mexico, Arizona, and southern Colorado	Warm moist to well-drained	Seral to *A. concolor* *P. menziesii*	*P. menziesii* *A. concolor* *P. strobiformis* *P. pungens* *P. engelmannii* *P. ponderosa* (NM) *A. lasiocarpa*	*A. glabrum* *B. repens* *Q. gambelii* *Holodiscus dumosus* *P. myrsinites* *B. repens*	Alexander et al. 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979 Youngblood 198
Abies concolor / Acer grandidentatum H.T.	Mountains of northern Arizona	Cool moist to warm well-drained	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. strobiformis* *P. ponderosa*	*A. grandidentatum* *Q. gambelii* *Carex foenea*	Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies concolor / Arctostaphylos uva-ursi H.T.	Mountains of northern New Mexico and southern Colorado	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. ponderosa* *P. flexilis*	*A. uva-ursi* *P. myrsinites*	DeVelice et al. 1984
Abies concolor / Berberis repens H.T.	Mountains of Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *A. grandis* *P. flexilis* *P. contorta* *P. ponderosa* *P. pungens*	*B. repens* *S. oreophilus* *Osmorhiza* spp. *L. leucanthus* *J. communis* *R. woodsii* *P. myrsinites*	Mauk and Hende son 1984 Youngblood 198
Abies concolor / Juglans major H.T.	Mountains of southern New Mexico	Warm moist	Seral to *A. concolor*	*A. concolor* *P. menziesii* *Populus angustifolia* *Fraxinus pennsylvanica*	*J. major* *Q. gambelii* *P. pratensis* *Vitis arizonica*	Alexander et al. 1984a Fitzhugh et al. 1984
Abies concolor / Juniperus communis H.T.	Mountains of central and southern Utah	Warm to cold dry	Seral to *A. concolor*	*A. concolor* *P. pungens* *P. menziesii* *P. flexilis*	*J. communis* *S. oreophilus* *R. woodsii* *B. repens* *C. rossii*	Youngblood 198

able A5.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. tremuloides*	Principal tree associates	Principal understory species	Authority
bies concolor / Physocarpus malvaceus H.T.	Mountains of northern Utah	Warm moist	Seral to *A. concolor*	*A. concolor* *P. menziesii* *A. grandis* *J. scopulorum*	*P. malvaceus* *Mitella stauropetala* *S. racemosa* *S. oreophilus*	Mauk and Henderson 1984
bies concolor / Quercus gambelii *. concolor-Pseudotsuga menziesii / Q. gambelii* H.T.]	Mountains of New Mexico, Arizona, and southern Colorado	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. ponderosa* *P. strobiformis* *J. scopulorum*	*Q. gambelii* *M. virescens* *F. arizonica*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
bies concolor / Robinia neomexicana H.T. *. concolor-Pseudotsuga menziesii / R. neomexicana* H.T.]	Mountains of New Mexico and Arizona	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. ponderosa* *P. strobiformis* *P. engelmannii*	*R. neomexicana* *S. oreophilus* *Q. gambelii*	Fitzhugh et al. 1984 Moir and Ludwig 1979
bies concolor / Symphoricarpos oreophilus H.T.	Mountains of central and southern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. ponderosa* *J. scopulorum*	*S. oreophilus* *R. woodsii* *A. alnifolia* *C. rossii* *P. fendleriana*	Youngblood 1984
bies concolor / Vaccinium myrtillus H.T.	Mountains of northern New Mexico and southern Colorado	Cool dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. pungens* *A. lasiocarpa* *P. engelmannii*	*V. myrtillus* *A. glabrum* *A. uva-ursi* *P. myrsinites* *Rubus parviflorus*	DeVelice et al. 1984
bies concolor / Elymus triticoides H.T. *A. concolor-Pseudotsuga menziesii / E. triticoides* H.T.]	Capitan Mountains, New Mexico	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. ponderosa* *P. strobiformis*	*E. triticoides* *Bromus richardsonii*	Moir and Ludwig 1979
bies concolor / Festuca arizonica H.T.	Mountains of northern New Mexico	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *P. ponderosa* *P. strobiformis*	*Q. gambelii* *F. arizonica* *Muhlenbergia* spp.	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
bies concolor / Poa fendleriana H.T. *A. concolor-Pseudotsuga menziesii / P. fendleriana* H.T.]	White Mountains, Arizona	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. strobiformis* *P. ponderosa*	*P. fendleriana* *Fragaria vesca* *Senecio wootonii* *Achillea lanulosa* *Geranium richardsonii* *Erigeron* spp.	Moir and Ludwig 1979
bies concolor / Erigeron eximius H.T. *A. concolor / Pseudotsuga menziesii / E. superbus* H.T.]	Mountains of northern New Mexico and Arizona	Cool moist	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. pungens* *P. engelmannii* *P. ponderosa* *P. strobiformis*	*E. superbus* (*E. eximius*) *C. foenea* *Lathyrus arizonicus* *Fragaria virginiana*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
bies concolor / Lathyrus arizonicus H.T. *A. concolor-Pseudotsuga menziesii / L. arizonicus* H.T.]	San Francisco Peaks, Arizona	Cool dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. ponderosa*	*L. arizonicus* *G. richardsonii*	Moir and Ludwig 1979

Table A5.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. tremuloides***	**Principal tree associates**	**Principal understory species**	**Authority**
Abies concolor / Osmorhiza chilensis H.T.	Wasatch Mountains, Utah	Warm moist	Seral to *A. concolor*	*A. concolor* *P. engelmannii* *P. menziesii* *A. grandis*	*O. chilensis* *P. malvaceus* *P. myrsinites* *P. virginiana*	Mauk and Hender son 1984
Abies concolor / Sparse H.T. [*A. concolor-Pseudotsuga menziesii* H.T.]	Mountains of New Mexico, Arizona, and southern Colorado	Warm dry	Seral to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. pungens* *P. strobiformis* *P. ponderosa*	*S. oreophilus* *R. neomexicana* *Q. gambelii* *B. repens*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
***Picea pungens* series**						
Picea pungens / Arctostaphylos uva-ursi [*P. pungens-Pseudotsuga menziesii / A. uva-ursi* H.T.]	Mountains of northern New Mexico and southern Colorado	Warm dry	Seral to *P. pungens* *P. menziesii* *A. concolor*	*A. concolor* *P. pungens* *P. menziesii* *P. ponderosa* *P. flexilis*	*A. uva-ursi* *J. communis* *F. arizonica* *F. ovalis*	DeVelice et al. 1984 Moir and Ludwig 1979
Picea pungens / Berberis repens H.T.	Mountains of Utah	Cool dry	Seral to *P. pungens*	*P. pungens* *P. menziesii* (minor climax) *P. contorta* *P. ponderosa* *P. flexilis* *J. scopulorum*	*B. repens* *J. communis* *P. myrsinites* *Aquilegia caerulea* *Pyrola secunda* *R. montigenum* *S. oreophilus*	Mauk and Hende son 1984 Youngblood 1984
Picea pungens / Cornus stolonifera H.T.	Mountains of north-central and northwestern New Mexico	Warm moist	Seral to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *Juniperus* spp.	*C. stolonifera* *B. repens* *P. myrsinites* *C. foenea*	Alexander et al. 1984c
Picea pungens / Juniperus communis H.T.	Mountains of central Utah	Cool dry	Seral to *P. pungens*	*P. pungens* *P. menziesii* *P. ponderosa* *P. flexilis* *J. scopulorum*	*J. communis* *A. uva-ursi* *S. oreophilus* *B. repens* *P. myrsinites*	Youngblood 1984
Picea pungens / Linnaea borealis H.T. [*P. pungens-Pseudotsuga menziesii / L. borealis* H.T.]	Sangre de Cristo Mountains, southern Colorado and northern New Mexico	Cool well-drained	Seral to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *A. concolor* *P. flexilis* *A. lasiocarpa* *P. engelmannii*	*L. borealis* *P. myrsinites* *V. myrtillus* *R. parviflorus*	DeVelice et al. 1984 Moir and Ludwig 1979
Picea pungens / Agropyron spicatum H.T.	Uinta Mountains, Utah	Warm dry	Seral to *P. pungens*	*P. pungens* *P. menziesii* *P. contorta* *P. flexilis* *J. scopulorum* *P. ponderosa*	*A. spicatum* *B. repens* *J. communis* *P. myrsinites*	Mauk and Hende son 1984
Picea pungens / Festuca arizonica H.T.	Jemez Mountains, New Mexico; San Juan Mountains, Colorado	Warm dry	Seral to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *A. concolor* *P. ponderosa*	*F. arizonica* *C. foenea* *Erigeron* spp. *Fragaria* spp.	DeVelice et al. 1984
Picea pungens / Poa pratensis H.T.	Mountains of New Mexico	Warm to cool moist	Seral to *P. pungens*	*P. pungens* *P. menziesii* *P. ponderosa* *A. concolor* *P. strobiformis*	*P. pratensis* *E. superbus* (*E. eximius*) *G. richardsonii* *F. virginiana*	Fitzhugh et al. 1984 Moir and Ludwig 1979

Table A5.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. tremuloides*	Principal tree associates	Principal understory species	Authority
icea pungens / Carex foenea H.T.	White Mountains and Kaibab Plateau, Arizona; mountains of northern New Mexico	Warm to cool moist	Seral to *P. engelmannii* *P. menziesii* *P. pungens*	*P. engelmannii* *P. menziesii* *P. pungens* *P. strobiformis* *A. concolor*	*C. foenea* *F. arizonica* *B. ciliatus*	Alexander et al. 1984c DeVelice et al. 1984 Moir and Ludwig 1979
cea pungens / Arnica cordifolia H.T.	Mountains of southern Wyoming, northern and central Colorado	Cool moist	Seral to *P. pungens*	*P. pungens* *P. menziesii*	*A. cordifolia* *S. stellata* *J. communis* *Calamagrostis canadensis*	Hess 1981
icea pungens / Equisetum arvense H.T.	Mountains of southern Utah	Warm to cool wet	Seral to *P. pungens*	*P. pungens* *P. engelmannii* *P. menziesii*	*E. arvense* *G. richardsonii* *T. fendleri* *O. chilensis*	Youngblood 1984
icea pungens / Erigeron eximius H.T. *P. pungens-Picea engelmannii / E. superbus* H.T.]	Mountains of Arizona, northern New Mexico, and southern Colorado	Cool dry	Seral to *P. pungens* *P. engelmannii* *P. menziesii* *A. concolor*	*P. pungens* *A. lasiocarpa* (minor climax) *P. menziesii* *A. concolor* *P. engelmannii* *P. strobiformis* *P. ponderosa* *P. flexilis*	*E. superbus* (*E. eximius*) *F. arizonica* *C. foenea* *F. virginiana* *G. richardsonii* *T. fendleri*	DeVelice et al. 1984 Moir and Ludwig 1979
icea pungens Fragaria ovalis H.T. *P. pungens-Pseudotsuga menziesii / Valeriana acutiloba* H.T.]	Mountains of New Mexico and eastern Arizona	Cool moist	Seral to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *P. strobiformis* *P. ponderosa* *A. concolor* *P. engelmannii* *A. lasiocarpa*	*F. ovalis* *V. acutiloba* *C. foenea* *F. arizonica* *E. superbus*	Alexander et al. 1984a Fitzhugh et al. 1984 Moir and Ludwig 1979
Picea pungens / Senecio cardamine H.T. *P. pungens-Picea engelmannii / S. cardamine* H.T.]	White Mountains, Arizona	Cool moist	Seral to *P. pungens* *P. engelmannii*	*P. pungens* *P. engelmannii* *A. lasiocarpa* (minor climax) *P. menziesii* *A. concolor* *P. strobiformis* *P. ponderosa*	*S. cardamine* *P. aquilinum* *Helenium hoopesii* *Viola canadensis*	Moir and Ludwig 1979
			***Picea glauca* series**			
Picea glauca / Linnaea borealis H.T.	Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Cool well-drained	Seral to *P. glauca*	*P. glauca* *P. ponderosa* *B. papyrifera*	*L. borealis* *S. canadensis* *Lonicera dioica*	Hoffman 1984
Picea glauca / Vaccinium scoparium H.T.	Black Hills and Bearlodge Mountains, South Dakota and eastern Wyoming	Cool well-drained	Seral to *P. glauca*	*P. glauca* *P. ponderosa* *B. papyrifera*	*V. scoparium* *Clematis tenuiloba*	Hoffman 1984
			***Abies grandis* series**			
Abies grandis / Spiraea betulifolia H.T.	Mountains of central Idaho	Warm dry	Seral to *A. grandis*	*A. grandis* *P. menziesii* *P. ponderosa*	*S. betulifolia* *C. rubescens* *A. cordifolia*	Steele et al. 1981

Table A5.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. tremuloides***	**Principal tree associates**	**Principal understory species**	**Authority**
			***Pinus contorta* series and other *P. contorta* dominated vegetation**			
Pinus contorta / Arctostaphylos uva-ursi H.T. (UT); P.C. (CO)	Uinta Mountains, Utah; mountains of central Colorado	Warm dry well-drained	Seral to *P. contorta* (UT) or to unknown ultimate climax (CO)	*P. contorta* *A. lasiocarpa* *P. engelmannii*	*A. uva-ursi* *B. repens* *Sitanion hystrix*	Mauk and Hende son 1984 Steen and Dix 19
Pinus contorta / Berberis repens C.T.	Uinta Mountains, Utah	Cool dry to well-drained	Seral to unknown ultimate climax	*P. contorta*	*B. repens* *C. geyeri* *P. myrsinites* *J. communis*	Mauk and Hende son 1984
Pinus contorta / Juniperus communis H.T. (CO); CT (UT)	Mountains of northern Utah; north-central Colorado	Warm dry	Seral to *P. contorta* (CO) or unknown ultimate climax (UT)	*P. contorta* *P. menziesii* *P. engelmannii* *A. lasiocarpa*	*J. communis* *A. uva-ursi* *S. canadensis* *A. cordifolia*	Hess 1981 Mauk and Hende son 1984
Pinus contorta / Pachistima myrsinites P.C.	Mountains of central Colorado	Warm dry to well-drained	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* *P. contorta*	*P. myrsinites* *V. scoparium* *J. communis* *L. borealis* *L. leucanthus*	Steen and Dix 19
Pinus contorta / Purshia tridentata H.T.	Mountains of western Montana	Cool-warm dry to well-drained	Seral to *A. lasiocarpa* *P. menziesii* *P. contorta*	*P. contorta* *A. lasiocarpa* *P. menziesii* *P. engelmannii*	*P. tridentata* *A. uva-ursi* *C. rossii* *F. idahoensis*	Pfister et al. 197
Pinus contorta / Shepherdia canadensis H.T. (CO); C.T. (WY,ID)	Mountains of Idaho, northwestern Wyoming; central and northern Colorado	Cool-warm dry to well-drained	Seral to *P. contorta* (CO) or unknown ultimate climax (WY,ID)	Usually only *P. contorta* but may contain *P. engelmannii* *P. menziesii* *A. lasiocarpa*	*S. canadensis* *P. myrsinites* *J. communis* *A. cordifolia* *L. borealis* *A. uva-ursi*	Hess 1981 Hess and Wasse 1981 Hoffman and Ale ander 1980 Steen and Dix 19 Steele et al. 198
Pinus contorta / Vaccinium myrtillus H.T.	Mountains of central Colorado	Cool dry	Seral to *P. contorta*	*P. contorta*	*V. myrtillus* *C. geyeri* *L. borealis* *P. myrsinites*	Hess 1981 Moir 1969
Pinus contorta / Carex geyeri H.T. (CO); C.T. (WY)	Mountains of southern Wyoming and north central Colorado	Cool dry	Seral to *P. contorta* (CO) or unknown ultimate climax (WY)	*P. contorta* *P. engelmannii* *A. lasiocarpa* *P. menziesii* *Pinus albicaulis* *P. flexilis*	*C. geyeri* *S. oreophilus* *A. cordifolia* *Lupinus argenteus* *B. repens* *J. communis*	Hess 1981 Hess and Wasse 1981 Steen and Dix 19 Wirsing and Ale ander 1975
Pinus contorta / Carex rossii H.T. (UT); C.T. (WY)	Mountains of northern Utah and northwestern Wyoming	Warm dry	Seral to *P. contorta* (UT) or to unknown ultimate climax (WY)	*P. contorta* *A. lasiocarpa* *P. engelmannii* *P. albicaulis*	*C. rossii* *L. argenteus* *P. nervosa*	Mauk and Hende son 1984 Steele et al. 198
Pinus contorta / Lupinus argenteus P.C.	Mountains of central and southern Colorado	Warm dry to well-drained	Seral to unknown ultimate climax	*P. contorta* *P. engelmannii* *A. lasiocarpa*	*L. argenteus*	Steen and Dix 19

able A5.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. tremuloides*	Principal tree associates	Principal understory species	Authority
			***Picea engelmannii* series**			
icea engelmannii / *Acer glabrum* H.T.	Chiricahua Mountains, Arizona; Sacramento Mountains, New Mexico	Warm moist	Seral to *P. engelmannii*	*P. engelmannii* *P. menziesii* *A. lasiocarpa*	*A. glabrum* *B. ciliatus* *V. canadensis* *S. stellata*	Alexander et al. 1984a Moir and Ludwig 1979
icea engelmannii / *Ribes montigenum* H.T.	Mountains of southern Utah	Cool dry	Seral to *P. engelmannii*	*P. engelmannii*	*R. montigenum* *C. rossii* *A. coerulea* *L. argenteus*	Youngblood 1984
icea engelmannii / *Vaccinium caespitosum* H.T.	Mountains of northern Utah	Cool well-drained	Seral to *P. engelmannii*	*P. engelmannii* *P. contorta*	*V. caespitosum* *Potentilla* spp. *Carex* spp.	Mauk and Henderson 1984
icea engelmannii / *Vaccinium myrtillus* H.T. *. engelmannii* / *V. myrtillus-Polenomium pulcherrimum* H.T.] *. engelmannii* / *Vaccinium scoparium-P. delicatum* H.T.]	Mountains of northern New Mexico and southern Colorado	Cool dry	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* *A. aristata*	*P. pulcherrimum* (P. delicatum) *Senecio* spp. *Poa reflexa* *Deschampsia caespitosa*	DeVelice et al. 1984 Moir and Ludwig 1979
icea engelmannii / *Elymus triticoides* H.T.	Capitan Mountains, New Mexico	Cool dry to well-drained	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* *P. menziesii*	*E. triticoides* *A. glabrum* *Jamesia americana*	Alexander et al. 1984a Moir and Ludwig 1979
icea engelmannii / *Arnica cordifolia* H.T.	Mountains of northwestern Wyoming	Cool well-drained	Seral to *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. flexilis* *P. albicaulis* *P. contorta*	*A. cordifolia* *C. rossii* *A. miser* *Frasera speciosa*	Steele et al. 1983
icea engelmannii / *Geum rossii* H.T.	San Francisco Peaks, Arizona	Cool dry	Seral to *P. engelmannii*	*P. engelmannii*	*G. rossii* *Polemonium delicatum* *Festuca brachyphylla*	Moir and Ludwig 1979
icea engelmannii / *Senecio cardamine* H.T.	Blue Mountains, Arizona	Cool moist	Seral to *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. ponderosa* *P. strobiformis* *A. concolor* *A. lasiocarpa* *P. pungens*	*S. cardamine* *F. ovalis* *G. richardsonii* *V. canadensis*	Fitzhugh et al. 1984
icea engelmannii / *Trifolium dasyphyllum* H.T.	High mountains of central Colorado	Cold moist	Seral to *P. engelmannii* *A. lasiocarpa*	*P. engelmannii* *A. lasiocarpa* *P. flexilis*	*T. dasyphyllum* *Pyrola chlorantha* *Sedum lanceolatum* *Trisetum spicatum*	Hess 1981
icea engelmannii / Moss spp. H.T.	Mountains of Arizona, New Mexico, and southern Colorado	Cool moist to well-drained	Seral to *P. engelmannii* *A. lasiocarpa*	*P. engelmannii* *A. lasiocarpa* *Pinus aristata* *P. menziesii*	Moss spp. *L. arizonicus* *V. scoparium* *A. glabrum* *Rosa* spp.	Alexander et al. 1984c Fitzhugh et al. 1984 Moir and Ludwig 1979

Table A5.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. tremuloides*	Principal tree associates	Principal understory species	Authority
			***Abies lasiocarpa* series**			
Abies lasiocarpa / Acer glabrum H.T.	Mountains of northern and central Utah; mountains of north-central and northwestern New Mexico	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. engelmannii* *A. concolor* *P. pungens* *P. contorta* *P. flexilis*	*A. glabrum* *Thalictrum occidentale* *T. fendleri* *O. chilensis* *A. cordifolia*	Alexander et al. 1984c Mauk and Hend son 1984 Youngblood 198
Abies lasiocarpa / Berberis repens H.T.	Mountains of Utah, northwestern Wyoming, and southeastern Idaho	Warm to cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. pungens* *P. engelmannii* *P. menziesii* *P. flexilis* *A. concolor* *A. contorta*	*B. repens* *R. montigenum* *C. geyeri* *P. myrsinites* *S. oreophilus*	Mauk and Hend son 1984 Steele et al. 198 Youngblood 198
Abies lasiocarpa / Juniperus communis H.T.	Mountains of northwestern Wyoming, Utah, northern Arizona, and New Mexico	Warm to cold dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta* *A. concolor* (AZ, NM) *P. pungens* *P. longaeva*	*J. communis* *P. secunda* *S. canadensis* *A. cordifolia* *S. oreophilus* *R. woodsii*	Mauk and Hend son 1984 Moir and Ludwi 1979 Steele et al. 198 Youngblood 198
Abies lasiocarpa / Linnaea borealis H.T. (ID,WY) *A. lasiocarpa-Picea engelmannii / L. borealis* P.C. (CO)	Mountains of southern Idaho, northwestern Wyoming, and central Colorado	Cool moist to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides* *P. ponderosa* *L. occidentalis*	*L. borealis* *A. cordifolia* *V. scoparium* *C. rubescens*	Steele et al. 198 Steen and Dix 1
Abies lasiocarpa / Pachistima myrsinites P.C. *A. lasiocarpa-Picea engelmannii / P. myrsinites* P.C.	Mountains of north-central Colorado	Warm dry to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta*	*P. myrsinites* *C. geyeri* *Erigeron* spp.	Steen and Dix 1
Abies lasiocarpa / Physocarpus malvaceus H.T.	Mountains of eastern Idaho, northwestern Wyoming, and northern and central Utah	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. engelmannii* *A. concolor*	*P. malvaceus* *A. cordifolia* *A. alnifolia* *Sorbus scopulina*	Mauk and Hend son 1984 Steele et al. 198 Youngblood 198
Abies lasiocarpa / Ribes montigenum H.T.	Mountains of Utah	Cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. engelmannii* *P. menziesii* *P. albicaulis*	*R. montigenum* *Arnica latifolia* *T. fendleri* *Antennaria microphylla* *Mertensia arizonica*	Mauk and Hend son 1984 Youngblood 198
Abies lasiocarpa / Rubus parviflorus H.T.	Mountains of New Mexico and southwestern Colorado	Warm moist	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. menziesii* *A. concolor* *P. engelmannii*	*R. parviflorus* *V. myrtillus* *A. glabrum* *P. myrsinites*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwi 1979
Abies lasiocarpa / Shepherdia canadensis P.C. *A. lasiocarpa-Picea engelmannii / S. canadensis* P.C.	Mountains of central Colorado	Cool-warm dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta*	*S. canadensis* *V. scoparium*	Steen and Dix 1

Table A5.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. tremuloides***	**Principal tree associates**	**Principal understory species**	**Authority**
bies lasiocarpa / Symphoricarpos albus H.T.	Mountains of southeastern Idaho	Warm well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta*	*S. albus* *A. alnifolia* *C. rubescens*	Steele et al. 1983
bies lasiocarpa / Vaccinium caespitosum H.T.	Mountains of northern and central Utah	Cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta*	*V. caespitosum* *L. borealis* *C. rubescens* *V. scoparium* *A. cordifolia*	Mauk and Henderson 1984 Youngblood 1984
bies lasiocarpa / Vaccinium globulare H.T.	Mountains of northern Utah	Cool moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. menziesii*	*V. globulare* *P. myrsinites* *A. cordifolia*	Mauk and Henderson 1984
bies lasiocarpa / Vaccinium membranaceum H.T.	Mountains of central Utah	Warm dry to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii*	*V. membranaceum* *C. rossii* *P. myrsinites*	Youngblood 1984
bies lasiocarpa / Vaccinium myrtillus H.T. *. lasiocarpa / V. myrtillus-Linnaea borealis* H.T.] *. lasiocarpa / V. myrtillus-Rubus parviflorus* H.T.] *. lasiocarpa / Vaccinium scoparium-L. borealis* H.T.]	Mogollon Plateau, Arizona; mountains of northern New Mexico and southern Colorado	Cool moist to well-drained	Seral to *A. lasiocarpa* (AZ) *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *A. concolor* *P. pungens* *P. flexilis* *P. aristata*	*V. myrtillus* *Disporum trachycarpum* *C. canadensis* *Polemonium flavum* *V. scoparium* *L. borealis* *R. parviflorus* *E. eximius* (*E. superbus*)	Alexander et al. 1984c DeVelice et al. 1984 Moir and Ludwig 1979
bies lasiocarpa / Vaccinium scoparium H.T. *. lasiocarpa-Picea engelmannii / V. scoparium* H.T. *P. engelmannii / V. scoparium* H.T.]	Mountains of Wyoming and Utah, south to New Mexico and Arizona	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. menziesii* *P. albicaulis*	*V. scoparium* *V. myrtillus* *A. cordifolia* *C. geyeri* *E. superbus* (*E. eximius*) *P. delicatum* *L. borealis* *P. myrsinites*	Hess 1981 Hoffman and Alexander 1980, 1983 Moir and Ludwig 1979 Pfister 1972 Steen and Dix 1974 Wirsing and Alexander 1975
bies lasiocarpa / Calamagrostis canadensis H.T. *Picea engelmannii / C. canadensis* H.T.]	Mountains of central and southern Idaho, western Wyoming, northern Utah, and north central Colorado	Cool wet	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. engelmannii* *P. menziesii* *P. pungens*	*C. canadensis* *Senecio triangularis* *Galium triflorum*	Hess 1981 Mauk and Henderson 1984 Steele et al. 1981
Abies lasiocarpa / Calamagrostis rubescens H.T.	Mountains of southern Idaho and northern Utah	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. engelmannii*	*C. rubescens* *O. chilensis* *C. geyeri* *A. cordifolia* *P. myrsinites*	Mauk and Henderson 1984 Steele et al. 1983
Abies lasiocarpa / Carex geyeri H.T., *A. lasiocarpa-Picea engelmannii / C. geyeri* P.C. *P. engelmannii / C. geyeri* H.T.]	Mountains of southern Utah, central and southern Wyoming, and north-central Colorado	Cool dry to warm dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis*	*C. geyeri* *A. cordifolia* *S. oreophilus* *L. argenteus* *B. repens* *Lathyrus lanszwertii*	Hess 1981 Hoffman and Alexander 1980, 1983 Steen and Dix 1974 Wirsing and Alexander 1975 Youngblood 1984

Table A5.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. tremuloides*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / *Carex rossii* H.T.	Mountains of southern Idaho, Utah, and western Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. engelmannii* (UT) *P. menziesii* (UT)	*C. rossii* *A. cordifolia* *A. miser* *R. woodsii*	Steele et al. 198 Youngblood 198
Abies lasiocarpa / *Aconitum columbianum* H.T.	Mountains of central and southern Utah	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *A. concolor*	*A. columbianum* *Actaea rubra* *A. cordifolia* *B. ciliatus*	Youngblood 198
Abies lasiocarpa / *Actaea rubra* H.T.	Mountains of northern Utah	Warm moist	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. pungens* *P. menziesii* *P. contorta*	*A. rubra* *O. chilensis* *Lonicera utahensis* *Vaccinium globulare*	Mauk and Hende son 1984
Abies lasiocarpa / *Arnica cordifolia* H.T.	Mountains of northwestern Wyoming	Cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. albicaulis* *P. engelmannii*	*A. cordifolia* *P. secunda* *A. miser* *F. virginiana*	Steele et al. 198
Abies lasiocarpa / *Arnica latifolia* H.T.	Mountains of southern Idaho and northern Utah	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta* *P. menziesii* *P. albicaulis*	*A. latifolia* *Aster engelmannii* *P. racemosa*	Steele et al. 198
Abies lasiocarpa-*Picea engelmannii* / *Cardamine cordifolia* P.C. [*A. lasiocarpa* / *Mertensia ciliata* H.T.]	Mountains of central and southern Colorado	Cool wet	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii*	*C. cordifolia* *M. ciliata* *Mitella pentandra* *Carex bella*	DeVelice et al. 1984 Steen and Dix 1
Abies lasiocarpa / *Erigeron superbus* (*E. eximius*) H.T.	Mountains of southwestern Colorado, northern New Mexico, and Arizona	Cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. ponderosa* *A. concolor* *P. menziesii* *P. strobiformis*	*E. superbus* (*E. eximius*) *G. richardsonii* *L. arizonicus* *L. involucrata* *A. cordifolia*	Alexander et al. 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies lasiocarpa / *Lathyrus arizonicus* H.T.	San Francisco Peaks, Arizona	Cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa*	*L. arizonicus* *G. richardsonii* *S. stellata*	Moir and Ludwig 1979
Abies lasiocarpa / *Osmorhiza chilensis* H.T.	Mountains of southern Idaho and northern Utah	Warm moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta*	*O. chilensis* *C. rossii* *B. repens* *P. myrsinites*	Mauk and Hende son 1984 Steele et al. 198
Abies lasiocarpa / *Pedicularis racemosa* H.T.	Mountains of northern Utah	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta*	*P. racemosa* *A. cordifolia* *S. oreophilus*	Mauk and Hende son 1984
Abies lasiocarpa / *Polemonium delicatum* P.C., *A. lasiocarpa*-*Picea engelmannii* / *P. delicatum* P.C.	High mountains of central and southern Colorado	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. contorta*	*P. delicatum* *Osmorhiza obtusa* *Vaccinium* spp.	Steen and Dix 1

Table A5.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. tremuloides*	Principal tree associates	Principal understory species	Authority
bies lasiocarpa / Senecio sanguisorboides H.T.	Sacramento Mountains, New Mexico	Cool dry to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii*	*S. sanguisorboides* *R. montigenum* *Ribes wolfii*	Alexander et al. 1984a Moir and Ludwig 1979
bies lasiocarpa / Thalictrum occidentale H.T.	Mountains of southeastern Idaho and northwestern Wyoming	Warm well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. contorta*	*T. occidentale* *O. chilensis* *A. cordifolia*	Steele et al. 1983
bies lasiocarpa / Moss spp. H.T. *. lasiocarpa-Picea engelmannii /* Moss spp. P.C.	Mountains of northern New Mexico, central and southern Colorado	Cool dry to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. aristata* *P. contorta* (CO) *P. menziesii*	Moss spp. *V. caespitosum* *Rosa* spp.	DeVelice et al. 1984 Steen and Dix 1974
			***Pinus aristata* series**			
inus aristata / Festuca arizonica H.T.	Sangre de Cristo Mountains, New Mexico	Warm dry	Seral to *P. aristata* *P. menziesii*	*P. aristata* *P. menziesii*	*F. arizonica* *K. cristata* *M. montana* *P. fendleriana*	DeVelice et al. 1984
			Riparian series			
lnus tenuifolia / Equisetum arvense H.T.	Streambanks, montane zone, north-central Colorado	Warm moist to wet	Seral to *A. tenuifolia*	*A. tenuifolia* *Betula occidentalis* *P. pungens*	*Salix* spp. *R. woodsii* *E. arvense* *A. glabrum*	Hess 1981
opulus angustifolia / Salix exigua H.T.	Streambanks, montane zone, north-central Colorado	Warm moist to wet	Seral to *P. angustifolia*	*P. angustifolia* *J. scopulorum* *P. pungens*	*Salix* spp. *A. glabrum*	Hess 1981

Table A6.—Habitat types, community types, and plant communities in which *Pinus contorta* is a climax, co-climax, minor climax, or seral.

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. contorta***	**Principal tree associates**	**Principal understory species**	**Authority**
			***Pinus contorta* series and other *P. contorta* dominated vegetation**			
Pinus contorta / Arctostaphylos uva-ursi H.T. (UT,WY); P.C. (CO)	Uinta Mountains, Utah; Bighorn Mountains, north-central Wyoming; mountains of north-central Colorado	Warm dry to well-drained	Climax or seral to unknown ultimate climax. Probably *Abies lasiocarpa* *Picea engelmannii*	*A. lasiocarpa* *P. engelmannii* *Populus tremuloides*	*A. uva-ursi* *Juniperus communis* *Spiraea betulifolia* *Carex rossii* *Berberis repens* *Sitanion hystrix*	Hoffmann and Alexander 197 Mauk and Hende son 1984 Steen and Dix 1
Pinus contorta / Berberis repens C.T.	Uinta Mountains, Utah	Cool dry to well-drained	Seral to unknown ultimate climax	*P. tremuloides*	*B. repens* *Carex geyeri* *Pachistima myrsinites* *J. communis*	Mauk and Hende son 1984
Pinus contorta / Juniperus communis H.T. (CO); C.T. (ID,WY,UT)	Mountains of eastern Idaho, northwestern Wyoming, northern Utah, and Colorado	Warm dry	Climax (CO) seral to unknown ultimate climax (ID,WY)	*Pseudotsuga menziesii* *P. tremuloides* *Pinus albicaulis* *P. engelmannii* *A. lasiocarpa*	*J. communis* *A. uva-ursi* *Shepherdia canadensis* *Arnica cordifolia*	Hess 1981 Komarkova 1984 Mauk and Hende son 1984 Steele et al. 198
Pinus contorta / Linnaea borealis C.T. (MT,WY); P.A. (CO)	Mountains of Montana east of Continental Divide, northwestern Wyoming, and central Colorado	Cool moist to well-drained	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii* (CO)	*A. lasiocarpa* *P. engelmannii* *P. menziesii*	*L. borealis* *Vaccinium scoparium* *Vaccinium globulare* *A. cordifolia* *Calamagrostis rubescens*	Pfister et al. 197 Steele et al. 198 Steen and Dix 1
Pinus contorta / Pachistima myrsinites P.C.	Mountains of north-central Colorado	Warm dry to well-drained	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*P. myrsinites* *V. scoparium* *J. communis* *L. borealis* *Lathyrus leucanthus*	Steen and Dix 19
Pinus contorta / Purshia tridentata H.T.	Mountains of western Montana	Cool-warm dry to well-drained	Climax or seral to *A. lasiocarpa* *P. menziesii*	*P. engelmannii* *A. lasiocarpa* *P. menziesii* *P. tremuloides*	*P. tridentata* *A. uva-ursi* *C. rossii* *Festuca idahoensis* *Epilobium angustifolium*	Pfister et al. 197
Pinus contorta / Shepherdia canadensis H.T. (CO); C.T. (ID,WY)	Mountains of southwest Idaho, northwest Wyoming, central and northern Colorado	Cool-warm dry to well-drained	Climax (CO) or seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii*	Usually in pure stands but may contain *A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides*	*S. canadensis* *P. myrsinites* *J. communis* *A. cordifolia* *L. borealis* *A. uva-ursi*	Hess 1981 Hess and Wasse 1982 Hoffman and Ale ander 1980 Steen and Dix 19 Steele et al. 1983
Pinus contorta / Spiraea betulifolia C.T.	Mountains of eastern Idaho and northwestern Wyoming	Warm dry	Seral to unknown ultimate climax. Probably *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. engelmannii*	*S. betulifolia* *C. rubescens* *C. geyeri*	Steele et al. 1983

able A6.—(continued)

abitat type, ommunity type, or lant community	**Location**	**Site**	**Successional status of *P. contorta***	**Principal tree associates**	**Principal understory species**	**Authority**
nus contorta / Vaccinium caespitosum C.T.	Mountains of south-central Montana, Idaho, and northern Utah	Cool well-drained	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii*	*V. caespitosum* *V. scoparium* *Festuca ovina* *L. borealis*	Cooper et al. 1983 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981
nus contorta / Vaccinium globulare C.T.	Mountains of southern Idaho, northwestern Wyoming, and northern Utah	Cool well-drained	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii*	*V. globulare* *Lonicera utahensis* *V. scoparium* *C. rubescens*	Steele et al. 1983
inus contorta / Vaccinium myrtillus H.T.	Mountains of north-central Colorado	Cool dry	Climax	*P. tremuloides*	*V. myrtillus* *C. geyeri* *L. borealis* *P. myrsinites*	Moir 1969
inus contorta / Vaccinium scoparium H.T. (CO); C.T. (ID,UT,WY)	Mountains of Montana, Idaho, and northern Wyoming; Uinta Mountains, Utah; mountains of southern Wyoming, western and central Colorado	Cool dry	Climax (CO) seral to unknown ultimate climax (ID,WY,UT)	Usually pure stands but may contain *P. engelmannii* *A. lasiocarpa* *P. menziesii* *P. albicaulis* *Pinus flexilis* *Abies grandis* *Larix occidentalis* *Tsuga heterophylla*	*V. scoparium* *A. cordifolia* *J. communis* *L. borealis* *C. rubescens* *Lupinus argenteus* *B. repens* *C. geyeri*	Cooper et al. 1983 Hess 1981 Hoffman and Alexander 1980 Komarkova 1984 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983 Steen and Dix 1974 Wirsing and Alexander 1975
inus contorta / Xerophyllum tenax C.T.	Mountains of northern Idaho	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii*	*X. tenax* *Vaccinium* spp.	Cooper et al. 1983
inus contorta / Calamagrostis canadensis C.T.	Uinta Mountains, Utah	Cool moist	Seral to unknown ultimate climax	*A. lasiocarpa* *P. engelmannii*	*C. canadensis* *A. cordifolia* *J. communis* *Poa nervosa*	Mauk and Henderson 1984
inus contorta / Calamagrostis rubescens C.T.	Mountains of Montana, Idaho, northeastern Utah, and northwestern Wyoming	Warm dry	Seral to unknown ultimate climax	*P. engelmannii* *A. lasiocarpa* *P. menziesii* *L. occidentalis*	*C. rubescens* *V. scoparium* *C. geyeri* *A. cordifolia* *A. uva-ursi*	Pfister 1977 Steele et al. 1983
inus contorta / Festuca idahoensis H.T.	Mountains of central Idaho	Warm dry to well-drained	Climax	*P. albicaulis* *P. menziesii*	*F. idahoensis* *C. rossii* *Penstemon* spp. *Artemisia* spp.	Steele et al. 1981
inus contorta / Carex geyeri H.T. (CO); C.T. (ID,WY)	Mountains of central Idaho, northwestern Wyoming, southern Wyoming, and Colorado	Cool dry	Climax (CO) seral to unknown ultimate climax (ID,WY)	Pure stands or occasionally with *P. engelmannii* *A. lasiocarpa* *P. menziesii* *P. albicaulis* *P. flexilis* *P. tremuloides*	*C. geyeri* *Symphoricarpos oreophilus* *A. cordifolia* *L. argenteus* *B. repens* *J. communis*	Hess 1981 Hess and Wasser 1982 Komarkova 1984 Steele et al. 1981, 1983 Steen and Dix 1974 Wirsing and Alexander 1975

Table A6.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. contorta*	Principal tree associates	Principal understory species	Authority
Pinus contorta / Carex rossii H.T. (UT); C.T. (WY)	Mountains of northern Utah and northwestern Wyoming	Warm dry	Climax (UT) seral to unknown ultimate climax (WY)	*A. lasiocarpa* *P. engelmannii* *P. albicaulis* *P. tremuloides*	*C. rossii* *L. argenteus* *P. nervosa*	Mauk and Hende son 1984 Steele et al. 198
Pinus contorta / Arnica cordifolia C.T.	Mountains of eastern Idaho and northwestern Wyoming	Cool dry	Seral to unknown ultimate climax	*A. lasiocarpa* *P. engelmannii* *P. albicaulis* *P. flexilis*	*A. cordifolia* *Antennaria racemosa* *Astragalus miser* *Pyrola secunda*	Steele et al. 198
Pinus contorta / Geranium fremontii H.T.	Front Range, north-central Colorado	Warm dry	Climax	Usually in pure stands. Occasionally *P. menziesii*	*G. fremontii* *A. uva-ursi* *J. communis*	Moir 1969
Pinus contorta / Lupinus argenteus P.C.	Mountains of central and southern Colorado	Warm dry to well-drained	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*L. argenteus*	Steen and Dix 1
Pinus contorta / Lichen spp. P.C.	Mountains of central Colorado	Hot dry	Seral to unknown ultimate climax. Probably *A. lasiocarpa*	*A. lasiocarpa*	Lichen spp.	Steen and Dix 1
			***Abies lasiocarpa* series**			
Abies lasiocarpa / Acer glabrum H.T.	Mountains of central and southern Idaho, northern Utah, and northwestern Wyoming	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides* *P. flexilis*	*A. glabrum* *Thalictrum occidentale* *Thalictrum fendleri* *Osmorhiza chilensis*	Mauk and Hend son 1984 Steele et al. 198 1983
Abies lasiocarpa / Alnus sinuata H.T.	Mountains of Montana, northern and central Idaho	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *L. occidentalis*	*A. sinuata* *V. scoparium* *X. tenax* *V. globulare*	Pfister et al. 19 Steele et al. 198
Abies lasiocarpa / Berberis repens H.T.	Mountains of northern Utah, northwestern Wyoming, and southeastern Idaho	Warm to cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *Picea pungens* *P. menziesii* *P. flexilis* *Abies concolor* *P. tremuloides*	*B. repens* *Ribes montigenum* *C. geyeri* *P. myrsinites*	Mauk and Hend son 1984 Pfister 1972 Steele et al. 198
Abies lasiocarpa / Clematis pseudoalpina H.T.	Mountains of Montana east of Continental Divide	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. flexilis* *P. menziesii* *P. albicaulis*	*C. pseudoalpina* *Clematis tenuiloba*	Pfister et al. 19
Abies lasiocarpa / Juniperus communis H.T.	Mountains of central Idaho, northwestern Wyoming, and northern Utah	Warm to cold dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides*	*J. communis* *P. secunda* *S. canadensis* *V. globulare*	Mauk and Hend son 1984 Steele et al. 198 1983

able A6.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. contorta*	Principal tree associates	Principal understory species	Authority
ies lasiocarpa / Linnaea borealis H.T. (MT,ID,WY) *lasiocarpa-Picea engelmannii / L. borealis* P.C. (CO)	Mountains of Montana, central and southern Idaho, northwestern Wyoming, central and southern Colorado	Cool moist to well-drained	Seral to *A. lasiocarpa* *P. engelmannii* (CO)	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides* *L. occidentalis* *Pinus ponderosa*	*L. borealis* *A. cordifolia* *V. scoparium* *C. rubescens*	Pfister et al. 1977 Steele et al. 1981, 1983 Steen and Dix 1974
ies lasiocarpa / Menziesia ferruginea H.T.	Mountains of southeastern Washington, eastern Oregon, Montana, Idaho, and northwestern Wyoming	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *Pinus monticola* *L. occidentalis* *P. albicaulis*	*M. ferruginea* *V. globulare* *Rhododendron albiflorum* *Ledum glandulosum* *Arnica latifolia* *Luzula hitchcockii*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981, 1983
ies lasiocarpa / Pachistima myrsinites H.T. (CO,ID,WA), *lasiocarpa-Picea engelmannii / P. myrsinites* P.C. (CO)	Mountains of eastern Washington, Idaho, central and southern Colorado	Warm dry to well-drained	Seral to *A. lasiocarpa* *P. engelmannii* (CO)	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. monticola* *P. tremuloides* *L. occidentalis*	*P. myrsinites* *Clintonia uniflora* *Galium triflorum* *C. geyeri* *Erigeron* spp.	Daubenmire and Daubenmire 1968 Hess and Wasser 1981 Steen and Dix 1974
bies lasiocarpa / Ribes montigenum H.T.	Mountains of Idaho, northern Utah, and northwestern Wyoming	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *P. albicaulis* *P. menziesii*	*R. montigenum* *A. latifolia* *T. fendleri* *Antennaria microphylla*	Mauk and Henderson 1984 Pfister 1972 Steele et al. 1981, 1983
bies lasiocarpa / Salix -seudolapponum H.T. *. lasiocarpa-Picea engelmannii / S. glauca* H.T.]	High mountains of Colorado	Cold wet	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. flexilis*	*S. pseudolapponum* *V. myrtillus* *Polemonium pulcherrimum* *Acomastylis rossii*	Hess 1981 Hess and Wasser 1982 Komarkova 1984
bies lasiocarpa / Shepherdia canadensis H.T. (WY) *lasiocarpa-Picea engelmannii / S. canadensis* P.C. (CO)	Bighorn Mountains, Wyoming; mountains of central Colorado	Cool-warm dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *P. menziesii*	*S. canadensis* *V. scoparium*	Hoffman and Alexander 1976 Steen and Dix 1974
bies lasiocarpa / Spiraea betulifolia H.T.	Mountains of central and southern Idaho, and northwestern Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. albicaulis*	*S. betulifolia* *C. geyeri* *C. rubescens* *P. myrsinites*	Steele et al. 1981, 1983
bies lasiocarpa / Symphoricarpos albus H.T.	Mountains of southeastern Idaho and northwestern Wyoming	Warm well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides*	*S. albus* *A. alnifolia* *C. rubescens*	Steele et al. 1983
bies lasiocarpa / Vaccinium caespitosum H.T.	Mountains of south-central Montana, central Idaho, and northern Utah	Cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*V. caespitosum* *L. borealis* *C. rubescens* *V. scoparium*	Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981
bies lasiocarpa / Vaccinium globulare H.T.	Mountains of south-central Montana, central and southern Idaho, northern Utah, and northwestern Wyoming	Cool moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides*	*V. globulare* *P. myrsinites* *L. utahensis* *A. cordifolia*	Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983

Table A6.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. contorta*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / Vaccinium scoparium H.T., *A. lasiocarpa-Picea engelmannii / V. scoparium* P.C. [*P. engelmannii / V. scoparium* H.T.]	Mountains of Montana and Idaho, south to central Colorado	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *L. occidentalis* *P. tremuloides* *P. menziesii* *P. albicaulis* *Pinus aristata*	*V. scoparium* *C. rubescens* *V. myrtillus* *A. cordifolia* *C. geyeri* *Polemonium delicatum (P. pulcherrimum)* *L. borealis* *P. myrsinites* *Phyllodoce empetriformis*	Daubenmire and Daubenmire 19 Hess 1981 Hess and Wasse 1982 Hoffman and Ale ander 1976, 19 1983 Mauk and Hende son 1984 Pfister 1972 Pfister et al. 197 Steele et al. 198 1983 Steen and Dix 19 Wirsing and Ale ander 1975
Abies lasiocarpa-Pinus albicaulis / Vaccinium scoparium H.T.	Mountains of Montana, east of Continental Divide	Cool dry	Seral to *A. lasiocarpa* *P. albicaulis*	*A. lasiocarpa* *P. albicaulis* *P. engelmannii*	*V. scoparium* *C. geyeri* *X. tenax* *A. latifolia*	Pfister et al. 197
Abies lasiocarpa / Xerophyllum tenax H.T.	Mountains of northern Idaho, eastern Washington and Oregon, southern Idaho, Montana, and northwestern Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. albicaulis* *P. menziesii* *P. ponderosa*	*X. tenax* *Vaccinium membranaceum* *V. scoparium* *V. globulare* *L. hitchcockii*	Cooper et al. 19 Daubenmire and Daubenmire 19 Pfister et al. 197 Steele et al. 198 1983
Abies lasiocarpa / Calamagrostis canadensis H.T. [*Picea engelmannii / C. canadensis* H.T.]	Mountains of central Montana, Idaho, northwestern Wyoming, northern Utah, and central Colorado	Cool wet	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *P. pungens* *P. menziesii*	*C. canadensis* *V. caespitosum* *L. glandulosum* *Senecio triangularis* *G. triflorum*	Cooper et al. 19 Hess 1981 Mauk and Hende son 1984 Pfister et al. 197 Steele et al. 198 1983
Abies lasiocarpa / Calamagrostis rubescens H.T.	Mountains of Montana east of Continental Divide, central and southern Idaho, northern Utah, and northwestern Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides*	*C. rubescens* *O. chilensis* *T. occidentale* *C. geyeri* *A. cordifolia* *P. myrsinites*	Mauk and Hende son 1984 Pfister et al. 197 Steele et al. 198 1983
Abies lasiocarpa / Luzula hitchcockii H.T.	Mountains of Montana west of Continental Divide, central and southern Idaho, and northwestern Wyoming	Cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. albicaulis*	*L. hitchcockii* *A. latifolia* *X. tenax* *A. cordifolia* *V. scoparium* *M. ferruginea*	Pfister et al. 197 Steele et al. 198 1983
Abies lasiocarpa / Carex geyeri H.T., *A. lasiocarpa-Picea engelmannii / C. geyeri* P.C. [*P. engelmannii / C. geyeri* H.T.]	Mountains of Montana, central Idaho, Wyoming, and Colorado	Cool to warm dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. albicaulis* *P. tremuloides*	*C. geyeri* *A. cordifolia* *S. oreophilus* *L. argenteus*	Hess 1981 Hess and Wass 1982 Hoffman and Al ander 1980, 19 Pfister et al. 197 Steele et al. 198 1983 Steen and Dix 1 Wirsing and Ale ander 1975

Table A6.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. contorta***	**Principal tree associates**	**Principal understory species**	**Authority**
Abies lasiocarpa / Carex rossii H.T.	Mountains of southern Idaho, northern Utah, and northwestern Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides*	*C. rossii*	Steele et al. 1983
Abies lasiocarpa / Actaea rubra H.T.	Mountains of central Idaho, northern Utah, and northwestern Wyoming	Warm moist	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. pungens* *V. globulare* *P. tremuloides*	*A. rubra* *O. chilensis* *L. utahensis* *V. globulare*	Mauk and Henderson 1984 Steele et al. 1983
Abies lasiocarpa / Arnica cordifolia H.T.	Mountains of Montana east of Continental Divide, central Idaho, northwestern and north-central Wyoming	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. albicaulis* *P. tremuloides*	*A. cordifolia* *P. secunda* *A. miser* *Fragaria virginiana*	Hoffman and Alexander 1976 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa / Arnica latifolia H.T.	Mountains of southern Idaho, northern Utah, and northwestern Wyoming	Cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *P. menziesii* *P. albicaulis*	*A. latifolia* *Aster engelmannii* *Pedicularis racemosa*	Steele et al. 1983
Abies lasiocarpa / Caltha biflora H.T.	Mountains of central Idaho	Cool wet	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii*	*C. biflora* *Lonicera involucrata* *Pedicularis bracteosa* *Dodecatheon jeffreyi*	Steele et al. 1981, 1983
Abies lasiocarpa / Clintonia uniflora H.T.	Mountains of northwestern Montana, northern and central Idaho	Warm moist to dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *L. occidentalis* *P. monticola* *P. ponderosa*	*C. uniflora* *M. ferruginea* *V. caespitosum* *Aralia nudicaulis* *X. tenax*	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981
Abies lasiocarpa / Coptis occidentalis H.T.	Mountains of northern Idaho	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *A. grandis* *L. occidentalis*	*C. occidentalis* *X. tenax* *V. globulare* *M. ferruginea*	Cooper et al. 1983
Abies lasiocarpa / Galium triflorum H.T.	Mountains of Montana	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *L. occidentalis*	*G. triflorum* *A. rubra* *Streptopus amplexifolius*	Pfister et al. 1977
Abies lasiocarpa-Picea engelmannii / Lupinus argenteus P.C.	Mountains of central and southern Colorado	Warm well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii*	*L. argenteus* *V. scoparium*	Steen and Dix 1974
Abies lasiocarpa / Osmorhiza chilensis H.T.	Mountains of southern Idaho and northern Utah	Warm moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides*	*O. chilensis* *C. rossii* *B. repens* *P. myrsinites*	Mauk and Henderson 1984 Steele et al. 1983
Abies lasiocarpa / Pedicularis racemosa H.T.	Mountains of southeastern Idaho, northwestern Wyoming, and northern Utah	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides*	*P. racemosa* *A. cordifolia* *S. oreophilus*	Mauk and Henderson 1984 Steele et al. 1983

Table A6.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. contorta*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa-Picea engelmannii / Polemonium delicatum P.C.	Mountains of central and southern Colorado	Cool dry	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*P. delicatum* *Osmorhiza obtusa* *Erigeron* spp.	Steen and Dix 19
Abies lasiocarpa / Streptopus amplexifolius H.T.	Mountains of central Idaho	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii*	*S. amplexifolius* *S. triangularis* *Ligusticum canbyi*	Steele et al. 1981
Abies lasiocarpa / Thalictrum occidentale H.T.	Mountains of southeastern Idaho and northwestern Wyoming	Warm well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. menziesii* *P. tremuloides*	*T. occidentale* *A. cordifolia* *O. chilensis*	Steele et al. 1983
Abies lasiocarpa-Picea engelmannii / Moss spp. P.C.	Mountains of central Colorado	Cool dry to well-drained	Seral to *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	Moss spp. *V. caespitosum* *Rosa* spp.	Steen and Dix 19
			***Picea engelmannii* series**			
Picea engelmannii / Juniperus communis H.T.	Mountains of northwestern Wyoming	Warm dry	Seral to *P. engelmannii*	*P. engelmannii* *P. flexilis* *P. menziesii* *P. albicaulis*	*J. communis* *A. cordifolia* *Frasera speciosa*	Steele et al. 1983
Picea engelmannii / Linnaea borealis H.T.	Mountains of Montana east of Continental Divide; Wind River Mountains, northwestern Wyoming	Cool well-drained	Seral to *P. engelmannii*	*P. engelmannii* *P. menziesii*	*L. borealis* *V. globulare* *S. albus* *J. communis*	Pfister et al. 1977 Steele et al. 1983
Picea engelmannii / Physocarpus malvaceus H.T.	Mountains of south-central Montana, eastern Idaho, and northwestern Wyoming	Warm moist	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* (minor climax) *P. menziesii*	*P. malvaceus* *G. triflorum* *S. albus* *S. betulifolia*	Pfister et al. 1977 Steele et al. 1983
Picea engelmannii / Ribes montigenum H.T.	Wind River Mountains, northwestern Wyoming; Aquarius Plateau, Utah	Cool dry to well-drained	Seral to *P. engelmannii*	*P. engelmannii* *P. albicaulis* *P. flexilis*	*R. montigenum* *Aquilegia caerulea* *Sibbaldia procumbens* *A. latifolia*	Pfister 1972 Steele et al. 1983
Picea engelmannii / Vaccinium caespitosum H.T.	Mountains of northwestern Montana and northern Utah	Cool well-drained	Seral to *P. engelmannii*	*P. engelmannii* *L. occidentalis* (MT) *P. ponderosa* (MT) *P. menziesii* (MT) *P. tremuloides* (UT)	*V. caespitosum* *L. borealis* *V. scoparium* *C. rubescens* *R. montigenum*	Mauk and Henderson 1984 Pfister et al. 1977
Picea engelmannii / Vaccinium scoparium H.T.	Wind River and Bighorn Mountains, Wyoming; mountains of northern Utah	Cool dry	Seral to *P. engelmannii*	*P. engelmannii* *P. flexilis* *P. menziesii* *P. albicaulis* *A. lasiocarpa* (minor climax WR Mts.)	*V. scoparium* *A. cordifolia* *C. rossii* *Antennaria* spp. *F. virginiana*	Hoffman and Alexander 1976 Mauk and Henderson 1984 Steele et al. 1983
Picea engelmannii / Carex disperma H.T.	Mountains of central and southern Idaho	Cool moist	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa*	*C. disperma* *P. secunda* *G. triflorum*	Steele et al. 1981

Table A6.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. contorta*	Principal tree associates	Principal understory species	Authority
cea engelmannii / *Arnica cordifolia* H.T.	Mountains of northwestern Wyoming	Cool well-drained	Seral to *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. tremuloides* *P. albicaulis* *P. flexilis*	*A. cordifolia* *C. rossii* *A. miser* *F. speciosa*	Steele et al. 1983
icea engelmannii / *Caltha leptosepala* H.T.	Uinta Mountains, Utah; mountains of northwestern Wyoming and southern Idaho	Cool moist	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* *P. albicaulis*	*C. leptosepala* *V. scoparium* *Deschampsia caespitosa*	Mauk and Henderson 1984 Steele et al. 1983
icea engelmannii / *Clintonia uniflora* H.T.	Mountains of northwestern Montana	Warm moist to dry	Seral to *P. engelmannii*	*P. engelmannii* *P. ponderosa* *P. menziesii* *L. occidentalis*	*C. uniflora* *V. caespitosum* *A. nudicaulis* *C. canadensis*	Pfister et al. 1977
icea engelmannii / *Equisetum arvense* H.T.	Mountains of Montana, central Idaho, northwestern Wyoming, northern Utah, central and southern Colorado	Warm to cool wet	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* *P. pungens*	*E. arvense* *Equisetum seirpoides* *S. amplexifolius* *S. triangularis* *Luzula parviflora*	Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1983
icea engelmannii / *Galium triflorum* H.T.	Mountains of south-central Montana, central Idaho, and northwestern Wyoming	Cool moist	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* *P. pungens* *P. ponderosa* *P. menziesii*	*G. triflorum* *A. rubra* *Smilacina stellata* *S. amplexifolius*	Pfister et al. 1977 Steele et al. 1981, 1983
icea engelmannii / *Smilacina stellata* H.T.	Mountains of Montana, east of Continental Divide	Warm moist	Seral to *P. engelmannii*	*P. engelmannii* *P. ponderosa* *P. menziesii*	*S. stellata* *Smilacina racemosa* *T. occidentale*	Pfister et al. 1977
***Picea pungens* series**						
icea pungens / *Berberis repens* H.T.	Mountains of Utah	Cool dry	Seral to *P. pungens*	*P. pungens* *P. menziesii* (minor climax) *P. tremuloides*	*B. repens* *J. communis* *P. myrsinites* *A. caerulea* *P. secunda* *R. montigenum*	Mauk and Henderson 1984 Pfister 1972
icea pungens / *Agropyron spicatum* H.T.	Uinta Mountains, Utah	Warm dry	Seral to *P. pungens*	*P. pungens* *P. menziesii* *P. tremuloides* *P. flexilis* *Juniperus scopulorum* *P. ponderosa*	*A. spicatum* *B. repens* *J. communis* *P. myrsinites*	Mauk and Henderson 1984
***Populas tremuloides* series and other *P. tremuloides* dominated vegetation**						
opulus tremuloides-Abies lasiocarpa / *Berberis repens* C.T. *. tremuloides* / *B. repens* C.T.	Mountains of western Wyoming	Warm to cool. Well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *P. flexilis*	*B. repens* *S. albus* *P. myrsinites*	Youngblood and Mueggler 1981
opulus tremuloides / *Juniperus communis* C.T.	Mountains of western Wyoming	Warm dry	Seral to unknown ultimate climax	*P. flexilis* *P. tremuloides*	*J. communis* *B. repens* *S. canadensis* *Rosa woodsii*	Youngblood and Mueggler 1981

Table A6.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. contorta*	Principal tree associates	Principal understory species	Authority
Populus tremuloides / Pachistima myrsinites P.C. (CO); C.T. (ID)	Mountains of southeastern Idaho, central and southwestern Colorado	Warm dry	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii* *P. menziesii*	*A. lasiocarpa* *V. scoparium* *P. menziesii* *P. tremuloides*	*P. myrsinites* *V. scoparium* *C. geyeri* *C. rubescens* *Geranium viscosissimum*	Mueggler and Campbell 1982 Steen and Dix 19
Populus tremuloides-Abies lasiocarpa / Prunus virginiana C.T., *P. tremuloides / P. virginiana* C.T.	Mountains of western Wyoming	Warm dry	Seral to *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. tremuloides*	*P. virginiana* *B. repens* *S. oreophilus* *R. woodsii*	Youngblood and Mueggler 1981
Populus tremuloides-Abies lasiocarpa / Shepherdia canadensis C.T., *P. tremuloides / S. canadensis* C.T.	Mountains of western Wyoming	Cool-dry to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *P. flexilis*	*S. canadensis* *G. viscosissimum* *A. cordifolia* *R. woodsii* *T. fendleri*	Youngblood and Mueggler 1981
Populus tremuloides-Pseudotsuga menziesii / Symphoricarpos oreophilus C.T., *P. tremuloides / S. oreophilus* C.T.	Mountains of southeastern Idaho	Warm dry	Seral to *P. menziesii*	*P. menziesii* *A. lasiocarpa* *P. tremuloides*	*S. oreophilus* *C. rubescens* *Poa pratensis* *T. fendleri* *L. argenteus*	Mueggler and Campbell 1982
Populus tremuloides-Pinus contorta / Calamagrostis rubescens C.T., *P. tremuloides / C. rubescens* C.T.	Mountains of southeastern Idaho	Warm dry	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. tremuloides*	*C. rubescens* *S. oreophilus* *P. myrsinites* *T. fendleri* *L. argenteus*	Mueggler and Campbell 1982
Populus tremuloides-Pseudotsuga menziesii / Calamagrostis rubescens C.T., *P. tremuloides / C. rubescens* C.T.	Mountains of southwestern Idaho	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. tremuloides*	*C. rubescens* *S. oreophilus* *T. fendleri* *A. cordifolia* *L. argenteus*	Mueggler and Campbell 1982
Populus tremuloides / Elymus glaucus P.C.	Mountains of central and southwestern Colorado	Warm moist to well-drained	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*E. glaucus* *A. alnifolia* *Symphoricarpos* spp. *Ligusticum porteri*	Steen and Dix 1 4
Populus tremuloides / Festuca thurberi P.C.	Mountains of central and southwestern Colorado	Warm dry	Seral to unknown ultimate climax. Probably *A. lasiocarpa* *P. engelmannii*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides* *P. menziesii*	*F. thurberi* *B. repens* *S. oreophilus* *Fragaria ovalis*	Steen and Dix 1 4
Populus tremuloides-Abies lasiocarpa / Arnica cordifolia C.T., *P. tremuloides / A. cordifolia* C.T.	Mountains of western Wyoming	Cool moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides*	*A. cordifolia* *S. oreophilus* *C. rossii* *O. chilensis* *P. nervosa*	Youngblood and Mueggler 1981

Table A6.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. contorta***	**Principal tree associates**	**Principal understory species**	**Authority**
opulus tremuloides / Equisetum arvense C.T.	Mountains of western Wyoming	Cool wet	Seral to *P. engelmannii*	*P. engelmannii* *A. lasiocarpa* *P. tremuloides*	*E. arvense* *E. glaucus* *T. fendleri*	Youngblood and Mueggler 1981
opulus tremuloides / Heracleum lanatum C.T.	Mountains of western Wyoming	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. engelmannii* *P. tremuloides*	*H. lanatum* *P. bracteosa* *T. fendleri* *E. glaucus*	Youngblood and Mueggler 1981
			***Thuja plicata* series**			
huja plicata / Pachistima myrsinites H.T.	Mountains of northern Idaho, eastern Washington, and Oregon	Warm dry to well-drained	Seral to *T. plicata*	*T. plicata* *P. monticola* *L. occidentalis* *P. menziesii* *P. engelmannii* *A. grandis*	*P. myrsinites* *A. glabrum* *G. triflorum*	Daubenmire and Daubenmire 1968
huja plicata / Clintonia uniflora H.T.	Mountains of northern Idaho and northwestern Montana	Cool to warm moist bottomlands	Seral to *T. plicata*	*T. plicata* *A. lasiocarpa* *A. grandis* *P. menziesii* *L. occidentalis* *P. engelmannii*	*C. uniflora* *A. nudicaulis* *M. ferruginea* *X. tenax*	Cooper et al. 1983 Pfister et al. 1977
			***Pinus ponderosa* series**			
inus ponderosa / Festuca idahoensis H.T.	Uinta Mountains, Utah	Warm dry	Seral to *P. ponderosa*	*P. ponderosa* *P. tremuloides* *J. scopulorum*	*F. idahoensis* *Arctostaphylos patula* *Artemisia tridentata*	Mauk and Henderson 1984
inus ponderosa / Carex geyeri H.T.	Uinta Mountains, Utah	Warm dry	Seral to *P. ponderosa*	*P. ponderosa* *P. tremuloides*	*C. geyeri* *A. alnifolia* *B. repens* *P. nervosa*	Mauk and Henderson 1984
			***Abies grandis* series**			
bies grandis / Linnaea borealis H.T.	Mountains of northern Idaho and central Montana	Cool moist to well-drained	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. engelmannii* *P. monticola* *P. menziesii* *L. occidentalis* *P. ponderosa*	*L. borealis* *Adenocaulon bicolor* *Disporum hookeri* *A. cordifolia* *Bromus vulgaris* *X. tenax* *V. globulare*	Cooper et al. 1983 Pfister et al. 1977
bies grandis / Pachistima myrsinites H.T.	Mountains of northern Idaho, eastern Washington, and eastern Oregon	Warm well-drained	Seral to *A. grandis*	*A. grandis* *P. menziesii* *L. occidentalis* *P. engelmannii* *P. monticola*	*P. myrsinites* *G. triflorum* *S. stellata* *T. occidentale*	Daubenmire and Daubenmire 1968
bies grandis / Physocarpus malvaceus H.T.	Mountains of northern Idaho	Warm dry	Seral to *A. grandis*	*A. grandis* *P. ponderosa* *P. menziesii* *L. occidentalis*	*P. malvaceus* *A. glabrum* *Holodiscus discolor* *S. racemosa*	Cooper et al. 1983
bies grandis / Spiraea betulifolia H.T.	Mountains of central Idaho	Warm dry	Seral to *A. grandis*	*A. grandis* *P. menziesii* *P. ponderosa* *P. tremuloides*	*S. betulifolia* *C. rubescens* *A. cordifolia*	Steele et al. 1981

Table A6.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. contorta*	Principal tree associates	Principal understory species	Authority
Abies grandis / Vaccinium caespitosum H.T.	Mountains of central Idaho	Cool well-drained	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. menziesii* *P. engelmannii* *L. occidentalis*	*V. caespitosum* *F. virginiana* *C. rubescens*	Steele et al. 1981
Abies grandis / Vaccinium globulare H.T.	Mountains of central Idaho	Cool well-drained	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. engelmannii* *P. menziesii*	*V. globulare*	Steele et al. 1981
Abies grandis / Xerophyllum tenax H.T.	Mountains of northwestern Montana and northern Idaho	Warm dry	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. menziesii* *P. engelmannii* *L. occidentalis* *P. ponderosa*	*X. tenax* *V. globulare* *C. rubescens* *P. myrsinites*	Cooper et al. 198 Pfister et al. 1977
Abies grandis / Calamagrostis rubescens H.T.	Mountains of central Idaho	Warm dry	Seral to *A. grandis*	*A. grandis* *P. menziesii* *P. ponderosa*	*C. rubescens* *C. geyeri* *A. cordifolia* *O. chilensis*	Steele et al. 1981
Abies grandis / Clintonia uniflora H.T.	Mountains of western Montana, central and northern Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. menziesii* *P. ponderosa* *P. engelmannii* *L. occidentalis*	*C. uniflora* *L. borealis* *A. bicolor* *P. malvaceus* *X. tenax* *A. glabrum*	Cooper et al. 198 Pfister et al. 1977 Steele et al. 1981
Abies grandis / Coptis occidentalis H.T.	Mountains of central and northern Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *P. menziesii* *P. ponderosa* *L. occidentalis* *A. lasiocarpa* *P. engelmannii*	*C. occidentalis* *P. malvaceus* *V. globulare* *X. tenax* *S. albus* *H. discolor*	Cooper et al. 198 Steele et al. 1981
			***Pseudotsuga menziesii* series**			
Pseudotsuga menziesii / Acer glabrum H.T.	Mountains of eastern Idaho, northern Utah, and northwestern Wyoming	Cool moist	Seral to *P. menziesii*	*P. menziesii* *P. tremuloides* *A. grandis* *P. flexilis*	*A. glabrum* *S. oreophilus* *A. alnifolia* *P. myrsinites*	Mauk and Henderson 1984 Steele et al. 1983
Pseudotsuga menziesii / Berberis repens H.T.	Mountains of southeast Idaho, northern Utah, north-central and northwestern Wyoming	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. flexilis* *P. tremuloides* *P. ponderosa* *J. scopulorum*	*B. repens* *S. oreophilus* *C. geyeri* *J. communis* *A. cordifolia*	Hoffman and Alexander 1976 Mauk and Henderson 1984 Steele et al. 1983
Pseudotsuga menziesii / Juniperus communis H.T.	Mountains of central and southwestern Montana, central Idaho, and northwestern Wyoming	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. flexilis* *S. canadensis*	*J. communis* *S. oreophilus* *S. canadensis* *A. cordifolia* *Juniperus horizontalis* *A. miser*	Pfister et al. 1977 Steele et al. 1981, 1983
Pseudotsuga menziesii / Linnaea borealis H.T.	Mountains of northwestern Montana and central Idaho	Warm moist to well-drained	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *L. occidentalis*	*L. borealis* *C. rubescens* *S. albus* *V. globulare*	Pfister et al. 1977 Steele et al. 1981

Table A6.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. contorta*	Principal tree associates	Principal understory species	Authority
seudotsuga menziesii / Pachistima myrsinites H.T.	Mountains of central Colorado	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. tremuloides* *P. engelmannii*	*P. myrsinites* *A. cordifolia* *B. repens* *V. myrtillus* *Q. gambelii*	Hess and Wasser 1982
Pseudotsuga menziesii / Physocarpus malvaceus H.T.	Mountains of Montana; Uinta Mountains, Utah	Warm moist to well-drained	Seral to *P. menziesii*	*P. menziesii* *L. occidentalis* *P. ponderosa* *P. tremuloides* *J. scopulorum*	*P. malvaceus* *Prunus virginiana* *H. discolor* *S. albus*	Mauk and Henderson 1984 Pfister et al. 1977
Pseudotsuga menziesii / Physocarpus monogynus H.T.	Bighorn Mountains, Wyoming	Warm well-drained	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *P. flexilis*	*P. monogynus* *B. repens* *S. oreophilus* *S. betulifolia*	Hoffman and Alexander 1976
Pseudotsuga menziesii / Spiraea betulifolia H.T.	Mountains of central and eastern Idaho, and northwestern Wyoming	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *P. flexilis*	*S. betulifolia* *C. rubescens* *P. myrsinites*	Steele et al. 1981, 1983
Pseudotsuga menziesii / Symphoricarpos albus H.T.	Mountains of central and eastern Idaho, southeastern Montana, and northwestern Wyoming	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *P. tremuloides*	*S. albus* *S. betulifolia* *A. uva-ursi* *B. repens*	Pfister et al. 1977 Steele et al. 1981, 1983
Pseudotsuga menziesii / Symphoricarpos oreophilus H.T.	Mountains of northern Utah and southern Idaho	Cool dry	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *P. flexilis* *P. tremuloides*	*S. oreophilus* *R. montigenum* *A. tridentata*	Mauk and Henderson 1984
Pseudotsuga menziesii / Vaccinium caespitosum H.T.	Mountains of northwestern Montana, central and northern Idaho	Cool moist to well-drained	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *L. occidentalis*	*V. caespitosum* *A. uva-ursi* *C. rubescens* *C. geyeri*	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981
Pseudotsuga menziesii / Vaccinium globulare H.T.	Mountains of north-central Montana, northern and eastern Idaho	Cool dry	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *L. occidentalis*	*V. globulare* *C. rubescens* *L. borealis* *S. betulifolia*	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981, 1983
Pseudotsuga menziesii / Calamagrostis rubescens H.T.	Mountains of eastern Washington and Oregon, Idaho, Montana, and northwestern Wyoming	Warm to cool dry to well-drained	Seral to *P. menziesii*	*P. menziesii* *P. ponderosa* *L. occidentalis* *P. tremuloides* *P. flexilis*	*C. rubescens* *C. geyeri* *A. cordifolia* *A. uva-ursi* *P. myrsinites* *A. spicatum*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981, 1983
Pseudotsuga menziesii / Carex geyeri H.T.	Mountains of central Idaho	Warm dry	Seral to *P. menziesii*	*P. menziesii* *P. tremuloides* *P. ponderosa*	*C. geyeri* *A. tridentata* *Lupinus* spp.	Steele et al. 1981
Pseudotsuga menziesii / Arnica cordifolia H.T.	Mountains of east-central Idaho and northwestern Wyoming	Cool to warm dry	Seral to *P. menziesii*	*P. menziesii* *P. flexilis*	*A. cordifolia* *A. miser* *S. oreophilus* *P. nervosa*	Steele et al. 1981, 1983

Table A6.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. contorta*	Principal tree associates	Principal understory species	Authority
Pseudotsuga menziesii / *Osmorhiza chilensis* H.T.	Mountains of southern Idaho and northern Utah	Warm well-drained	Seral to *P. menziesii*	*P. menziesii* *P. tremuloides* *A. grandis* *J. scopulorum*	*O. chilensis* *S. racemosa* *Viola nuttallii* *P. virginiana* *A. cordifolia*	Mauk and Henderson 1984 Steele et al. 1983
Abies concolor series						
Abies concolor / *Berberis repens* H.T.	Mountains of northern Utah	Warm dry	Seral to *A. concolor*	*A. concolor* *P. menziesii* *A. grandis*	*B. repens* *Osmorhiza* spp. *A. alnifolia* *C. geyeri*	Mauk and Henderson 1984
Tsuga heterophylla series						
Tsuga heterophylla / *Clintonia uniflora* H.T.	Mountains of northern Idaho and northwestern Montana	Warm moist	Seral to *T. heterophylla* *T. plicata*	*T. heterophylla* *T. plicata* *P. monticola* *P. engelmannii* *P. menziesii* *L. occidentalis*	*C. uniflora* *A. nudicaulis* *M. ferruginea* *X. tenax* *L. borealis*	Cooper et al. 198 Pfister et al. 1977
Tsuga mertensiana series						
Tsuga mertensiana / *Menziesia ferruginea* H.T.	Mountains of northern Idaho, eastern Washington, and eastern Oregon	Cool moist	Seral to *T. mertensiana*	*T. mertensiana* *A. lasiocarpa* *L. occidentalis* *P. engelmannii*	*M. ferruginea* *X. tenax* *R. albiflorum*	Cooper et al. 198 Daubenmire and Daubenmire 19 Pfister et al. 1977
Tsuga mertensiana / *Xerophyllum tenax* H.T.	Mountains of northern Idaho and northwestern Montana	Warm dry	Seral to *T. mertensiana*	*T. mertensiana* *A. lasiocarpa* *P. menziesii* *P. engelmannii* *P. albicaulis* *P. monticola* *L. occidentalis*	*X. tenax* *V. membranaceum* *V. globulare*	Daubenmire and Daubenmire 19 Pfister et al. 1977
Tsuga mertensiana / *Luzula hitchcockii* H.T.	Mountains of Montana, west of Continental Divide	Cool well-drained	Seral to *T. mertensiana* *A. lasiocarpa*	*T. mertensiana* *A. lasiocarpa* *P. albicaulis* *P. engelmannii*	*L. hitchcockii* *V. scoparium* *X. tenax* *A. latifolia*	Pfister et al. 1977
Tsuga mertensiana / *Clintonia uniflora* H.T.	Mountains of northern Idaho	Warm moist	Seral to *T. mertensiana*	*T. mertensiana* *P. menziesii* *P. engelmannii* *A. lasiocarpa* *A. grandis*	*C. uniflora* *M. ferruginea* *X. tenax*	Cooper et al. 198
Pinus flexilis series						
Pinus flexilis / *Juniperus communis* H.T.	Mountains of northwestern Wyoming	Warm dry	Minor climax to *P. flexilis*	*P. flexilis* *P. menziesii* *P. ponderosa* *P. tremuloides*	*J. communis* *S. canadensis* *A. cordifolia*	Steele et al. 1983
Pinus albicaulis series						
Pinus albicaulis / *Juniperus communis* H.T.	Mountains of southeastern Idaho and northwestern Wyoming	Cool dry	Co-climax with *P. albicaulis*	*P. albicaulis* *P. flexilis*	*J. communis* *S. canadensis* *A. miser*	Steele et al. 1983

Table A6.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. contorta***	**Principal tree associates**	**Principal understory species**	**Authority**
Pinus albicaulis / *Vaccinium scoparium* H.T.	Mountains of northwestern Wyoming	Cool dry	Co-climax with *P. albicaulis*	*P. albicaulis* *A. lasiocarpa* *P. engelmannii*	*V. scoparium* *C. rossii* *A. cordifolia*	Steele et al. 1983
Pinus albicaulis / *Carex geyeri* H.T.	Mountains of northwestern Wyoming	Cool dry	Co-climax with *P. albicaulis*	*P. albicaulis*	*C. geyeri* *F. idahoensis* *Trisetum spicatum*	Steele et al. 1983
Pinus albicaulis / *Carex rossii* H.T.	Mountains of northwestern Wyoming	Cool dry	Seral to *P. albicaulis*	*P. albicaulis* *A. lasiocarpa* *P. engelmannii*	*C. rossii*	Steele et al. 1983

Table A7.—Habitat types, community types, and plant communities in which *Picea engelmannii* is climax, co-climax, minor climax, or seral.

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. engelmannii***	**Principal tree associates**	**Principal understory species**	**Authority**
			***Picea engelmannii* series**			
Picea engelmannii / *Acer glabrum* H.T.	Chiricahua Mountains, Arizona; Sacramento Mountains, New Mexico	Warm moist	Climax	*Abies lasiocarpa* *Pseudotsuga menziesii* *Populus tremuloides*	*A. glabrum* *Bromus ciliatus* *Viola canadensis* *Smilacina stellata*	Alexander et al. 1984a Moir and Ludwi 1979
Picea engelmannii / *Juniperus communis* H.T.	Mountains of northwestern Wyoming	Warm dry	Climax	*Pinus flexilis* *P. menziesii* *Pinus albicaulis* *Pinus contorta*	*J. communis* *Arnica cordifolia* *Frasera speciosa*	Steele et al. 198
Picea engelmannii / *Linnaea borealis* H.T.	Mountains of Montana east of Continental Divide; Wind River Mountains, northwestern Wyoming	Cool well-drained	Climax	*P. contorta* *P. menziesii*	*L. borealis* *Vaccinium globulare* *Symphoricarpos albus* *J. communis*	Pfister et al. 19 Steele et al. 198
Picea engelmannii / *Physocarpus malvaceus* H.T.	Mountains of south-central Montana, eastern Idaho, and northwestern Wyoming	Warm moist	Climax	*A. lasiocarpa* (minor climax) *P. contorta* *P. menziesii*	*P. malvaceus* *Galium triflorum* *S. albus* *Spiraea betulifolia*	Pfister et al. 19 Steele et al. 198
Picea engelmannii / *Ribes montigenum* H.T.	Wind River Mountains, northwestern Wyoming; mountains of southern Utah	Cool dry to well-drained	Climax	*P. contorta* *P. albicaulis* *P. tremuloides* *P. flexilis*	*R. montigenum* *Aquilegia caerulea* *Sibbaldia procumbens* *Arnica latifolia* *Astragalus miser*	Pfister 1972 Steele et al. 198 Youngblood 198
Picea engelmannii / *Vaccinium caespitosum* H.T.	Mountains of northwestern Montana and northern Utah	Cool well-drained	Climax	*P. menziesii* *Larix occidentalis* *Pinus ponderosa* *P. contorta* *P. tremuloides*	*V. caespitosum* *L. borealis* *Vaccinium scoparium* *Calamagrostis rubescens* *R. montigenum*	Mauk and Hend son 1984 Pfister et al. 197
Picea engelmannii / *Vaccinium myrtillus* H.T. [*P. engelmannii* / *V. myrtillus*-*Polemonium pulcherrimum* H.T.] [*P. engelmannii* / *Vaccinium scoparium*-*P. delicatum* H.T.]	Sangre de Cristo Mountains, southern Colorado and northern New Mexico	Cool dry	Climax	*A. lasiocarpa* (minor climax) *Pinus aristata* *P. tremuloides*	*P. delicatum* (*P. pulcherrimum*) *Senecio* spp. *Deschampsia caespitosa* *Poa reflexa*	DeVelice et al. 1984 Moir and Ludwig 1979
Picea engelmannii / *Vaccinium scoparium* H.T.	Wind River and Bighorn Mountains, Wyoming; mountains of northern Utah	Cool dry	Climax	*A. lasiocarpa* (minor climax WR Mts) *P. flexilis* *P. contorta* *P. menziesii* *P. albicaulis*	*V. scoparium* *A. cordifolia* *Carex rossii* *Antennaria* spp. *Fragaria virginiana*	Hoffman and Ale ander 1976 Mauk and Hende son 1984 Steele et al. 1983
Picea engelmannii / *Bromus ciliatus* H.T	Mogollon and Black Mountains, New Mexico	Cool dry	Climax	*P. menziesii*	*B. ciliatus* *S. stellata* *Lathyrus arizonicus* *V. canadensis*	Fitzhugh et al. 1984

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
Picea engelmannii / *Elymus triticoides* H.T.	Capitan Mountains, New Mexico	Cool dry to well-drained	Climax or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. tremuloides*	*E. triticoides* *A. glabrum* *Jamesia americana*	Alexander et al. 1984a Moir and Ludwig 1979
Picea engelmannii / *Carex disperma* H.T.	Mountains of central and southern Idaho, and northwestern Wyoming	Cool moist	Climax	*A. lasiocarpa* *P. contorta* *Picea pungens*	*C. disperma* *Pyrola secunda* *G. triflorum*	Steele et al. 1981, 1983
Picea engelmannii / *Carex foenea* H.T.	Pinaleno Mountains, Arizona	Cool dry	Climax	Generally in pure stands	*C. foenea*	Moir and Ludwig 1979
Picea engelmannii / *Arnica cordifolia* H.T.	Mountains of northwestern Wyoming	Cool well-drained	Climax	*P. menziesii* *P. flexilis* *P. albicaulis* *P. tremuloides* *P. contorta*	*A. cordifolia* *C. rossii* *A. miser* *F. speciosa*	Steele et al. 1983
Picea engelmannii / *Caltha leptosepala* H.T.	Uinta Mountains, Utah; mountains of northwestern Wyoming and Idaho	Cool moist	Climax	*A. lasiocarpa* *P. contorta* *P. albicaulis*	*C. leptosepala* *V. scoparium* *D. caespitosa*	Mauk and Henderson 1984 Steele et al. 1983
Picea engelmannii / *Clintonia uniflora* H.T.	Mountains of northwestern Montana	Warm moist to dry	Climax	*P. menziesii* *P. contorta* *P. ponderosa* *L. occidentalis*	*C. uniflora* *V. caespitosum* *Aralia nudicaulis* *Cornus canadensis*	Pfister et al. 1977
Picea engelmannii / *Equisetum arvense* H.T.	Mountains of Montana, central Idaho, northwestern Wyoming, and northern Utah	Warm to cool wet	Climax	*A. lasiocarpa* *P. contorta* *P. pungens*	*E. arvense* *Equisetum scirpoides* *Streptopus amplexifolius* *Senecio triangularis* *Luzula parviflora*	Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983
Picea engelmannii / *Galium triflorum* H.T.	Mountains of south-central Montana, central Idaho, and northwestern Wyoming	Cool moist	Climax	*A. lasiocarpa* *P. contorta* *P. pungens* *P. ponderosa* *P. menziesii*	*G. triflorum* *Actaea rubra* *S. stellata* *S. amplexifolius*	Pfister et al. 1977 Steele et al. 1981, 1983
Picea engelmannii / *Geum rossii* H.T.	San Francisco Peaks, Arizona	Cool dry	Climax	*P. tremuloides*	*G. rossii* *P. delicatum* (*P. pulcherrimum*) *Festuca brachyphylla*	Moir and Ludwig 1979
Picea engelmannii / *Hypnum revolutum* H.T.	Mountains of central and southeastern Idaho, and northwestern Wyoming	Cool dry	Climax	*P. flexilis* *P. albicaulis* *P. menziesii*	*H. revolutum* *Discranowiesia crispula*	Steele et al. 1981, 1983
Picea engelmannii / *Saxifraga bronchialis* H.T. (Scree Forest)	Mountains of northern New Mexico and southern Colorado	Warm dry	Climax	*A. lasiocarpa* (minor climax)	*S. bronchialis* *J. communis*	DeVelice et al. 1984

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
Picea engelmannii / *Senecio cardamine* H.T.	Blue Mountains, Arizona	Cool moist	Climax	*A. lasiocarpa* *P. menziesii* *P. ponderosa* *Pinus strobiformis* *Abies concolor* *P. pungens* *P. tremuloides*	*S. cardamine* *Geranium richardsonii* *Fragaria ovalis* *V. canadensis*	Fitzhugh et al. 1984
Picea engelmannii / *Senecio streptanthifolius* H.T.	Mountains of central and southwestern Montana	Cool dry to well-drained	Climax	*P. menziesii* *P. flexilis* *P. albicaulis*	*S. streptanthifolius* *P. secunda* *A. cordifolia*	Pfister et al. 197
Picea engelmannii / *Smilacina stellata* H.T.	Mountains of Montana east of Continental Divide	Warm moist	Climax	*P. menziesii* *P. contorta* *P. ponderosa*	*S. stellata* *Smilacina racemosa* *Thalictrum occidentale*	Pfister et al. 197
Picea engelmannii / *Trifolium dasyphyllum* H.T.	Mountains of central Colorado	Cold moist	Climax or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides* *P. flexilis*	*T. dasyphyllum* *Pyrola chlorantha* *Sedum lanceolatum* *Trisetum spicatum*	Hess 1981
Picea engelmannii / Moss spp. H.T.	Mountains of New Mexico and Arizona	Cool moist to well-drained	Climax or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides* *P. aristata* *P. menziesii*	Moss spp. *Ribes* spp. *L. arizonicus* *Vaccinium* spp. *Rosa* spp.	Alexander et al. 1984c Fitzhugh et al. 1984 Moir and Ludwig 1979
***Abies lasiocarpa* series**						
Abies lasiocarpa / *Acer glabrum* H.T.	Mountains of central and southern Idaho, northern and central Utah, and northwestern Wyoming; mountains of north-central and northwestern New Mexico	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta* *P. tremuloides* *P. pungens* *A. concolor* *P. flexilis*	*A. glabrum* *T. occidentale* *Thalictrum fendleri* *Osmorhiza chilensis* *A. cordifolia* *B. repens* *B. ciliatus*	Alexander et al. 1984c Mauk and Henderson 1984 Steele et al. 1981, 1983 Youngblood 1984
Abies lasiocarpa / *Alnus sinuata* H.T.	Mountains of central and southwestern Montana, and central Idaho	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta* *L. occidentalis*	*A. sinuata* *V. scoparium* *Xerophyllum tenax* *V. globulare*	Pfister et al. 1977 Steele et al. 1981
Abies lasiocarpa / *Berberis repens* H.T.	Mountains of Utah, northwestern Wyoming; and southeastern Idaho	Warm to cool well-drained	Minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. pungens* *P. contorta* *P. menziesii* *P. flexilis* *A. concolor* *P. tremuloides*	*B. repens* *R. montigenum* *Carex geyeri* *Pachistima myrsinites* *Symphoricarpos oreophilus* *J. communis*	Mauk and Henderson 1984 Pfister 1972 Steele et al. 1983 Youngblood 1984
Abies lasiocarpa / *Clematis pseudoalpina* H.T.	Mountains of Montana east of Continental Divide	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. flexilis* *P. contorta* *P. menziesii* *P. albicaulis*	*C. pseudoalpina* *Clematis tenuiloba*	Pfister et al. 1977

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
bies lasiocarpa / Juniperus communis H.T.	Mountains of central Idaho, northwestern Wyoming, and Utah; mountains of northern Arizona and New Mexico	Warm to cold dry	Seral to or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta* *P. tremuloides* *A. concolor* (AZ,NM only) *P. pungens* (UT) *Pinus longaeva* (UT)	*J. communis* *P. secunda* *Shepherdia canadensis* *V. globulare* *Rosa woodsii* *S. oreophilus*	Mauk and Henderson 1980 Moir and Ludwig 1979 Steele et al. 1981, 1983 Youngblood 1984
Abies lasiocarpa / Linnaea borealis H.T. (MT,ID,WY) *A. lasiocarpa-Picea engelmannii / L. borealis* P.C. (CO)	Mountains of Montana, central and southern Idaho, northwestern Wyoming, and central Colorado	Cool moist to well-drained	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. tremuloides* *L. occidentalis* *P. ponderosa*	*L. borealis* *A. cordifolia* *V. scoparium* *C. rubescens* *Rubus parviflorus*	Pfister et al. 1977 Steele et al. 1981, 1983 Steen and Dix 1974
Abies lasiocarpa / Menziesia ferruginea H.T.	Mountains of southeastern Washington, eastern Oregon, Montana, Idaho, and northwestern Wyoming	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *Pinus monticola* *L. occidentalis* *P. albicaulis*	*M. ferruginea* *V. globulare* *Rhododendron albiflorum* *Ledum glandulosum* *A. latifolia* *X. tenax*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa / Oplopanax horridum H.T.	Mountains of northern Montana	Cool moist to wet	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. monticola* *P. menziesii* *L. occidentalis*	*O. horridum* *Taxus brevifolia*	Pfister et al. 1977
Abies lasiocarpa / Pachistima myrsinites H.T., *A. lasiocarpa-Picea engelmannii / P. myrsinites* P.C. (CO)	Mountains of eastern Washington and northern Idaho; mountains of central and southern Colorado	Warm dry to well-drained	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. monticola* *P. tremuloides* *L. occidentalis*	*P. myrsinites* *Clintonia uniflora* *G. triflorum* *C. geyeri* *Erigeron* spp.	Daubenmire and Daubenmire1968 Hess and Wasser 1982 Steen and Dix 1974
Abies lasiocarpa / Physocarpus malvaceus H.T.	Mountains of eastern Idaho, northwestern Wyoming, and northern and central Utah	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. tremuloides* *A. concolor*	*P. malvaceus* *A. cordifolia* *Amelanchier alnifolia* *Sorbus scopulina* *A. glabrum* *S. canadensis*	Mauk and Henderson 1984 Steele et al. 1983 Youngblood 1984
Abies lasiocarpa / Ribes montigenum H.T.	Mountains of southern Montana, Idaho, Utah, and northwestern Wyoming	Cool dry	Seral to or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides* *P. menziesii* *P. albicaulis*	*R. montigenum* *A. latifolia* *T. fendleri* *Antennaria microphylla* *Mertensia arizonica*	Mauk and Henderson 1984 Pfister 1972 Pfister et al. 1977 Steele et al. 1981, 1983 Youngblood 1984
Abies lasiocarpa / Rubus parviflorus H.T.	Mimbres and Mogollon Mountains, New Mexico; San Juan Mountains, Colorado	Warm moist	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *A. concolor* *P. tremuloides*	*R. parviflorus* *Vaccinum myrtillus* *A. glabrum* *P. myrsinites*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies lasiocarpa / Salix pseudolapponum H.T. [*A. lasiocarpa-Picea engelmannii / S. glauca* H.T.]	High mountains of Colorado	Cold wet	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. flexilis*	*S. pseudolapponum* *V. myrtillus* *P. pulcherrimum* *Acomastylis rossii*	Hess 1981 Hess and Wasser 1982 Komarkova 1984

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / Shepherdia canadensis H.T. (WY) *A. lasiocarpa-Picea engelmannii / S. canadensis* P.C. (CO)	Bighorn Mountains, north-central Wyoming; mountains of north-central Colorado	Cool to warm dry	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta* *P. tremuloides*	*S. canadensis* *V. scoparium*	Hoffman and Alexander 1976 Steen and Dix 197
Abies lasiocarpa / Spiraea betulifolia H.T.	Mountains of southern Idaho, and northwestern Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. albicaulis*	*S. betulifolia* *C. geyeri* *C. rubescens* *P. myrsinites*	Steele et al. 1983
Abies lasiocarpa / Symphoricarpos albus H.T.	Mountains of southeastern Idaho, and northwestern Wyoming	Warm well-drained lower slopes	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. tremuloides*	*S. albus* *A. alnifolia* *C. rubescens*	Steele et al. 1983
Abies lasiocarpa / Vaccinium caespitosum H.T.	Mountains of south-central Montana, central Idaho, northern and central Utah	Cool well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides* *P. menziesii*	*V. caespitosum* *L. borealis* *C. rubescens* *V. scoparium* *A. cordifolia*	Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981 Youngblood 1984
Abies lasiocarpa / Vaccinium globulare H.T.	Mountains of south-central Montana, central southern Idaho, northern Utah, and northwestern Wyoming	Cool moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. tremuloides* (UT)	*V. globulare* *P. myrsinites* *Lonicera utahensis* *A. cordifolia*	Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa / Vaccinium membranaceum H.T.	Mountains of central Utah	Warm dry to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides*	*V. membranaceum* *P. myrsinites* *C. rossii*	Youngblood 1984
Abies lasiocarpa / Vaccinium myrtillus H.T. [*A. lasiocarpa / V. myrtillus-Linnaea borealis* H.T.] [*A. lasiocarpa / V. myrtillus-Rubus parviflorus* H.T.] [*A. lasiocarpa / Vaccinium scoparium-L. borealis* H.T.]	Mountains of eastern Arizona, northern New Mexico, and southern Colorado; LaSal Mountains, Utah	Cool well-drained	Climax (AZ) or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *A. concolor* *P. menziesii* *P. tremuloides* *P. aristata* *P. flexilis* *P. pungens* *P. strobiformis*	*V. myrtillus* *V. scoparium* *Lonicera involucrata* *P. myrsinites* *A. cordifolia* *R. montigenum* *L. borealis* *R. parviflorus*	Alexander et al. 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979 Youngblood 1984
Abies lasiocarpa / Vaccinium scoparium H.T. *A. lasiocarpa-Picea engelmannii / V. scoparium* H.T.; P.C. [*P. engelmannii / V. scoparium* H.T.]	Mountains of Montana and Idaho south to Arizona and New Mexico	Cool dry	Climax, co-climax with or minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *L. occidentalis* *P. tremuloides* *P. menziesii* *P. albicaulis*	*V. scoparium* *C. rubescens* *V. myrtillus* *A. cordifolia* *C. geyeri* *Erigeron superbus* (*E. eximius*) *L. borealis* *P. myrsinites* *Phyllodoce empetriformis*	Daubenmire and Daubenmire 196 Hess 1981 Hess and Wasser 1982 Hoffman and Alexander 1976, 1980, 1983 Komarkova 1984 Mauk and Henderson 1984 Moir and Ludwig 1979 Pfister 1972 Pfister et al. 1977 Steele et al. 1981, 1983 Steen and Dix 1974 Wirsing and Alexander 1975

able A7.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
ies lasiocarpa- Pinus albicaulis / Vaccinium scoparium H.T.	Mountains of Montana east of Continental Divide	Cool dry	Seral to *A. lasiocarpa* *P. albicaulis*	*A. lasiocarpa* *P. albicaulis* *P. contorta*	*V. scoparium* *C. geyeri* *X. tenax* *A. latifolia*	Pfister et al. 1977
ies lasiocarpa / Xerophyllum tenax H.T.	Mountains of northern Idaho, eastern Washington and Oregon, southern Idaho, Montana, and northwestern Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. albicaulis* *P. contorta* *P. menziesii* *P. ponderosa*	*X. tenax* *V. membranaceum* *V. scoparium* *V. globulare* *Luzula hitchcockii*	Cooper et al. 1983 Daubenmire and Daubenmire 1968 Pfister et al. 1977 Steele et al. 1981, 1983
bies lasiocarpa / Calamagrostis canadensis H.T. *lasiocarpa- Picea engelmannii / C. canadensis* H.T. *. engelmanii / C. canadensis* H.T.]	Mountains of central Montana, Idaho, northwestern Wyoming, northern Utah, north-central and western Colorado	Cool wet	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides* *P. menziesii* *P. pungens*	*C. canadensis* *V. caespitosum* *L. glandulosum* *S. triangularis* *G. triflorum*	Cooper et al. 1983 Hess 1981 Komarkova 1984 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983
bies lasiocarpa / Calamagrostis rubescens H.T.	Mountains of Montana east of Continental Divide, southern Idaho, and northwestern Wyoming	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. tremuloides*	*C. rubescens* *O. chilensis* *T. occidentale* *C. geyeri* *A. cordifolia* *P. myrsinites*	Pfister et al. 1977 Steele et al. 1983
bies lasiocarpa / Luzula hitchcockii H.T.	Mountains of Montana west of Continental Divide, Idaho, and northwestern Wyoming	Cool well-drained	Seral or minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. albicaulis*	*L. hitchcockii* *A. latifolia* *X. tenax* *A. cordifolia* *V. scoparium* *M. ferruginea*	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981, 1983
bies lasiocarpa / Carex geyeri H.T., *. lasiocarpa- Picea engelmannii- C. geyeri* H.T.; P.C. *. engelmannii / C. geyeri* H.T.]	Mountains of Idaho, southern Utah, Wyoming, north-central and western Colorado	Cool dry to warm dry	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta* *P. albicaulis* *P. tremuloides*	*C. geyeri* *A. cordifolia* *S. oreophilus* *Lupinus argenteus* *B. repens* *Lathyrus lanszwertii*	Hess 1981 Hess and Wasser 1981 Hoffman and Alexander 1980, 1983 Komarkova 1984 Steele et al. 1981, 1983 Steen and Dix 1974 Wirsing and Alexander 1975 Youngblood 1984
bies lasiocarpa Carex rossii H.T.	Mountains of central and southern Utah	Cool dry	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. tremuloides*	*C. rossii* *A. cordifolia* *A. miser* *R. woodsii*	Youngblood 1984
bies lasiocarpa / Aconitum columbianum H.T.	Mountains of southern and central Utah	Cool moist	Seral to or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. tremuloides* *A. concolor*	*A. columbianum* *Actaea rubra* *A. cordifolia* *B. ciliatus*	Youngblood 1984
bies lasiocarpa / Actaea rubra H.T.	Mountains of central Idaho, northern Utah, and northwestern Wyoming	Warm moist	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. pungens* *P. contorta* *P. menziesii* *P. tremuloides*	*A. rubra* *O. chilensis* *L. utahensis* *V. globulare*	Mauk and Henderson 1984 Steele et al. 1983

Table A7.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. engelmannii***	**Principal tree associates**	**Principal understory species**	**Authority**
Abies lasiocarpa / Arnica cordifolia H.T.	Mountains of Montana east of Continental Divide, central Idaho, northwestern and north-central Wyoming, and western Colorado	Cool well-drained	Seral to or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. albicaulis* *P. tremuloides*	*A. cordifolia* *P. secunda* *A. miser* *F. virginiana* *[P. tremuloides]*	Hoffman and Ale ander 1976 Komarkova 1984 Pfister et al. 1977 Steele et al. 1981 1983
Abies lasiocarpa / Arnica latifolia H.T.	Mountains of southern Idaho, northern Utah, and northwestern Wyoming	Cool dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides* *P. menziesii* *P. albicaulis*	*A. latifolia* *Aster engelmannii* *Pedicularis racemosa*	Steele et al. 1983
Abies lasiocarpa / Caltha biflora H.T.	Mountains of central Idaho	Cool wet	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta*	*C. biflora* *L. involucrata* *Pedicularis bracteosa* *Dodecatheon jeffreyi*	Steele et al. 1981
Abies lasiocarpa-Picea engelmannii / Cardamine cordifolia P.C. [*A. lasiocarpa / Mertensia ciliata* H.T.]	Mountains of central and southern Colorado	Cool wet	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides*	*C. cordifolia* *Mertensia ciliata* *Mitella pentanda* *Carex bella*	DeVelice et al. 1984 Steen and Dix 19
Abies lasiocarpa / Clintonia uniflora H.T.	Mountains of northwestern Montana, northern and central Idaho	Warm moist to dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *L. occidentalis* *P. monticola* *A. grandis* *P. ponderosa*	*C. uniflora* *M. ferruginea* *V. caespitosum* *A. nudicaulis* *X. tenax*	Cooper et al. 198 Pfister et al. 1977 Steele et al. 1981
Abies lasiocarpa / Coptis occidentalis H.T.	Mountains of central and northern Idaho	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *L. occidentalis* *P. contorta* *A. grandis*	*C occidentalis* *X. tenax* *V. globulare* *M. ferruginea*	Cooper et al. 198 Steele et al. 1981
Abies lasiocarpa / Erigeron superbus (*E. eximius*) H.T.	Mountains of southwestern Colorado, northern New Mexico, and Arizona	Cool dry	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. ponderosa* *A. concolor* *P. menziesii* *P. strobiformis* *P. tremuloides* *P. pungens*	*E. superbus* (*E. eximius*) *G. richardsonii* *L. arizonicus* *L. involucrata* *A. cordifolia* *B. repens*	Alexander et al. 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies lasiocarpa / Galium triflorum H.T.	Mountains of Montana	Warm moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *L. occidentalis*	*G. triflorum* *A. rubra* *S. amplexifolius*	Pfister et al. 1977
Abies lasiocarpa-Picea engelmannii / Lupinus argenteus P.C.	Mountains of central and southern Colorado	Warm well-drained	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta*	*L. argenteus* *V. scoparium*	Steen and Dix 19
Abies lasiocarpa / Osmorhiza chilensis H.T.	Mountains of southern Idaho and northern Utah	Warm moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta* *P. tremuloides*	*O. chilensis* *C. rossii* *B. repens* *P. myrsinites*	Mauk and Hende son 1984 Steele et al. 1983

Table A7.—(continued)

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *P. engelmannii***	**Principal tree associates**	**Principal understory species**	**Authority**
bies lasiocarpa / Pedicularis racemosa H.T.	Mountains of southeastern Idaho, northwestern Wyoming, and northern Utah	Warm dry	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta* *P. tremuloides*	*P. racemosa* *A. cordifolia* *S. oreophilus*	Mauk and Henderson 1984 Steele et al. 1983
bies lasiocarpa / Polemonium delicatum H.T., *. lasiocarpa-Picea engelmannii / P. delicatum* P.C.	Mountains of central and western Colorado	Cool dry	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides*	*P. delicatum* *Osmorhiza obtusa* *Vaccinium* spp.	Komarkova 1984 Steen and Dix 1974
bies lasiocarpa / Senecio sanguisorboides H.T.	Sacramento Mountains, southern New Mexico	Cool dry to well-drained	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. tremuloides*	*S. sanguisorboides* *R. montigenum* *Ribes wolfii*	Alexander et al. 1984a Moir and Ludwig 1979
bies lasiocarpa / Senecio triangularis H.T., *icea engelmannii / S. triangularis* H.T. *P. engelmannii / S. triangularis* H.T.]	Mountains of central and western Colorado	Cool wet	Co-climax with *A. lasiocarpa*	*A. lasiocarpa*	*S. triangularis* *M. ciliata* *C. cordifolia* *E. arvense*	Hess 1981 Komarkova 1984
bies lasiocarpa / Streptopus amplexifolius H.T.	Mountains of Idaho to northwestern Utah	Warm to moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta*	*S. amplexifolius* *S. triangularis* *A. columbianum* *Ligusticum canbyi*	Cooper et al. 1983 Steele et al. 1981, 1983
bies lasiocarpa / Thalictrum occidentale H.T.	Mountains of southeastern Idaho and northwestern Wyoming	Warm well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta* *P. tremuloides*	*T. occidentale* *A. cordifolia* *O. chilensis*	Steele et al. 1983
bies lasiocarpa / Moss spp. H.T., *. lasiocarpa-Picea engelmannii* / Moss spp. P.C.	Mountains of northern New Mexico, and southern and western Colorado	Cool dry	Co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides* *P. aristata* *P. contorta* (CO) *P. menziesii* (NM)	Moss spp. *Rosa* spp. *V. caespitosum*	DeVelice et al. 1984 Komarkova 1984 Steen and Dix 1974
Picea pungens series						
Picea pungens / Linnaea borealis H.T. *P. pungens-Pseudotsuga menziesii / L. borealis* H.T.]	Sangre de Cristo Mountains, southern Colorado and northern New Mexico	Cool well-drained	Minor climax to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *A. concolor* *P. tremuloides* *A. lasiocarpa*	*L. borealis* *P. myrsinites* *V. myrtillus*	DeVelice et al. 1984 Moir and Ludwig 1979
Picea pungens / Carex foenea H.T.	Mountains of north-central and northwestern New Mexico	Cool moist	Minor climax to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *P. tremuloides*	*C. foenea* *A. glabrum* *Festuca arizonica* *E. eximius* (*E. superbus*)	Alexander et al. 1984c
Picea pungens / Equisetum arvense H.T.	Mountains of southern Utah	Warm to cool wet	Minor climax to *P. pungens*	*P. pungens* *P. menziesii* *P. tremuloides*	*E. arvense* *G. richardsonii* *T. fendleri* *O. chilensis*	Youngblood 1984

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
Picea pungens / Erigeron eximius H.T. [*P. pungens*-*Picea engelmannii / E. superbus* H.T.]	Mountains of northern New Mexico and southern Colorado	Cool dry	Minor climax to *P. pungens* *P. menziesii* *A. concolor*	*A. lasiocarpa* (minor climax) *P. pungens* *P. menziesii* *A. concolor* *P. tremuloides* *P. strobiformis* *P. ponderosa* *P. flexilis*	*E. superbus* (*E. eximius*) *F. arizonica* *C. foenea* *F. virginiana* *G. richardsonii* *T. fendleri*	DeVelice et al. 1984 Moir and Ludwig 1979
Picea pungens / Fragaria ovalis H.T.	Mountains of New Mexico	Cool moist	Minor climax to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *P. ponderosa* *P. strobiformis* *P. tremuloides* *A. concolor* *A. lasiocarpa*	*F. ovalis* *C. foenea* *F. arizonica* *E. superbus* (*E. eximius*)	Alexander et al. 1984a Fitzhugh et al. 1984
Picea pungens / Senecio cardamine H.T. [*P. pungens*-*Picea engelmannii / S. cardamine* H.T.]	White Mountains, Arizona	Cool moist	Co-climax with *P. pungens*	*A. lasiocarpa* (minor climax) *P. pungens* *P. menziesii* *A. concolor* *P. strobiformis* *P. tremuloides* *P. ponderosa*	*S. cardamine* *Pteridium aquilinum* *Helenium hoopesii* *V. canadensis*	Moir and Ludwig 1979
***Pinus contorta* series and other *P. contorta* dominated vegetation**						
Pinus contorta / Arctostaphylos uva-ursi H.T. (UT); P.C. (CO)	Uinta Mountains, Utah; mountains of north-central Colorado	Warm dry	Minor climax to *P. contorta* (UT). Ultimate climax unknown (CO). Probably co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides* *P. contorta*	*A. uva-ursi* *B. repens* *Sitanion hystrix*	Mauk and Hender son 1984 Steen and Dix 19
Pinus contorta / Juniperus communis H.T. (CO); C.T. (ID,WY)	Mountains of eastern Idaho, northwestern Wyoming, and north-central Colorado	Warm dry	Minor climax to *P. contorta* (CO). Ultimate climax unknown (ID,WY). Probably seral to or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. tremuloides* *P. albicaulis*	*J. communis* *A. uva-ursi* *S. canadensis* *A. cordifolia*	Hess 1981 Steele et al. 1983
Pinus contorta / Linnaea borealis C.T. (MT,WY); P.C. (CO)	Mountains of Montana east of Continental Divide, northwestern Wyoming, and north-central Colorado	Cool moist to well-drained	Ultimate climax unknown. Probably seral to or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta*	*L. borealis* *V. scoparium* *V. globulare* *A. cordifolia* *C. rubescens*	Pfister et al. 1977 Steele et al. 1983 Steen and Dix 19

able A7.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
nus contorta / Pachistima myrsinites P.C.	Mountains of north-central Colorado	Warm dry to well-drained	Ultimate climax unknown. Probably co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides* *P. contorta*	*P. myrsinites* *V. scoparium* *J. communis* *L. borealis* *Lathyrus leucanthus*	Steen and Dix 1974
inus contorta / Purshia tridentata H.T.	Mountains of western Montana	Cool-warm dry to well-drained	Seral to *P. menziesii* *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta* *P. tremuloides*	*P. tridentata* *A. uva-ursi* *C. rossii* *Lupinus* spp. *Epilobium angustifolium*	Pfister et al. 1977
inus contorta / Shepherdia canadensis C.T. (ID,WY); P.C. (CO)	Mountains of southeastern Idaho, northwestern Wyoming and central Colorado	Cool-warm dry to well-drained	Ultimate climax unknown. Probably co-climax with *P. menziesii* *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta* *P. tremuloides*	*S. canadensis* *A. cordifolia* *J. communis* *L. borealis* *A. uva-ursi*	Steen and Dix 1974 Steele et al. 1983
inus contorta / Spiraea betulifolia C.T.	Mountains of eastern Idaho and northwestern Wyoming	Warm dry	Ultimate climax unknown. Probably seral or minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *P. contorta*	*S. betulifolia* *C. rubescens* *C. geyeri*	Steele et al. 1983
inus contorta / Vaccinium caespitosum C.T.	Mountains of south-central Montana, Idaho, and northern Utah	Cool well-drained	Ultimate climax unknown. Probably seral or minor climax to *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. contorta*	*V. caespitosum* *V. scoparium* *Festuca ovina* *L. borealis*	Cooper et al. 1983 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981
Pinus contorta / Vaccinium globulare C.T.	Mountains of southern Idaho, northwestern Wyoming, and northern Utah	Cool well-drained	Ultimate climax unknown. Probably seral or minor climax to *A. lasiocarpa* *P. menziesii*	*A. lasiocarpa* *P. menziesii* *P. contorta*	*V. globulare* *L. utahensis* *V. scoparium* *C. rubescens*	Steele et al. 1983
Pinus contorta / Vaccinium scoparium C.T.; P.C. (CO)	Mountains of Montana, Idaho, and northwestern Wyoming; Uinta Mountains of Utah, mountains of southern Wyoming and central Colorado	Cool to cold dry	Ultimate climax unknown. Probably minor climax to or co-climax with *A. lasiocarpa*	*P. menziesii* *A. lasiocarpa* *P. albicaulis* *P. flexilis* *Abies grandis* *Tsuga heterophylla* *L. occidentalis* *P. contorta*	*V. scoparium* *C. rubescens* *A. cordifolia* *L. argenteus* *B. repens* *C. geyeri* *Ribes cereum* *L. borealis*	Cooper et al. 1983 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983 Steen and Dix 1974 Wirsing and Alexander 1975

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
Pinus contorta / *Xerophyllum tenax* C.T.	Mountains of northern Idaho	Warm dry	Ultimate climax unknown. Probably seral to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii*	*X. tenax* *Vaccinium* spp.	Cooper et al. 1984
Pinus contorta / *Calamagrostis canadensis* C.T.	Uinta Mountains, Utah	Cool moist	Ultimate climax unknown. Probably seral or minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta*	*C. canadensis* *A. cordifolia* *J. communis* *Poa nervosa*	Mauk and Henderson 1984
Pinus contorta / *Calamagrostis rubescens* C.T.	Mountains of Montana, Idaho, northeastern Utah, and northwestern Wyoming	Warm dry	Ultimate climax unknown. Probably seral or minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *L. occidentalis* *P. contorta*	*C. rubescens* *V. scoparium* *C. geyeri* *A. cordifolia* *A. uva-ursi*	Pfister et al. 1977 Steele et al. 1983
Pinus contorta / *Carex geyeri* H.T. (CO); C.T. (ID,WY)	Mountains of central Idaho, northwestern Wyoming, southern Wyoming, and north-central Colorado	Cool dry	Ultimate climax unknown. Probably seral to or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. albicaulis* *P. flexilis* *P. tremuloides*	*C. geyeri* *S. oreophilus* *A. cordifolia* *L. argenteus* *B. repens* *J. communis*	Hess 1981 Hess and Wasser 1982 Steele et al. 1981, 1983 Steen and Dix 197 Wirsing and Alexander 1975
Pinus contorta / *Carex rossii* C.T.	Mountains of northwestern Wyoming	Warm dry	Ultimate climax unknown. Probably seral to or co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides* *P. albicaulis*	*C. rossii* *L. argenteus* *P. nervosa*	Steele et al. 1983
Pinus contorta / *Arnica cordifolia* C.T.	Mountains of eastern Idaho and northwestern Wyoming	Cool dry	Ultimate climax unknown. Probably seral or minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. albicaulis* *P. flexilis* *P. contorta*	*A. cordifolia* *Antennaria racemosa* *A. miser* *P. secunda*	Steele et al. 1983
Pinus contorta / *Lupinus argenteus* P.C.	Mountains of central and southern Colorado	Warm dry to well-drained	Ultimate climax unknown. Probably co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides* *P. contorta*	*L. argenteus*	Steen and Dix 197
	Populus tremuloides series and other _P. tremuloides_ dominated vegetation					
Populus tremuloides-*Abies lasiocarpa* / *Berberis repens* C.T., *P. tremuloides* / *B. repens* C.T.	Mountains of western Wyoming	Warm to cool well-drained	Seral or minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides*	*B. repens* *S. albus* *P. myrsinites*	Youngblood and Mueggler 1981

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
opulus tremuloides / Pachistima myrsinites P.C.	Mountains of central and southwestern Colorado	Warm dry	Ultimate climax unknown. Probably co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides*	*P. myrsinites* *V. scoparium* *C. geyeri*	Steen and Dix 1974
opulus tremuloides-Abies lasiocarpa / Shepherdia canadensis C.T., *. tremuloides / S. canadensis* C.T.	Mountains of western Wyoming	Cool dry to well-drained	Minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. flexilis* *P. tremuloides*	*S. canadensis* *A. cordifolia* *R. woodsii* *T. fendleri*	Youngblood and Mueggler 1981
opulus tremuloides / Elymus glaucus P.C.	Mountains of central and southwestern Colorado	Warm moist to well-drained	Ultimate climax unknown. Probably co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides*	*E. glaucus* *A. alnifolia* *Symphoricarpos* spp. *Ligusticum porteri*	Steen and Dix 1974
Populus tremuloides / Festuca thurberi P.C.	Mountains of southwestern Colorado	Warm dry	Ultimate climax unknown. Probably co-climax with *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. menziesii* *P. tremuloides*	*F. thurberi* *B. repens* *S. oreophilus* *F. ovalis*	Steen and Dix 1974
Populus tremuloides / Equisetum arvense C.T.	Mountains of western Wyoming	Cool wet	Probably climax	*A. lasiocarpa* *P. contorta* *P. tremuloides*	*E. arvense* *E. glaucus* *T. fendleri*	Youngblood and Mueggler 1981
Populus tremuloides / Heracleum lanatum C.T.	Mountains of western Wyoming	Warm moist	Seral or minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. contorta* *P. tremuloides*	*H. lanatum* *P. bracteosa* *T. fendleri* *E. glaucus*	Youngblood and Mueggler 1981
Populus tremuloides-Abies lasiocarpa / Ligusticum filicinum C.T., *P. tremuloides / L. filicinum* C.T.	Mountains of western Wyoming	Cool moist to well-drained	Minor climax to *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides*	*L. filicinum* *T. fendleri* *Geranium viscosissimum* *Osmorhiza occidentalis*	Youngblood and Mueggler 1981
Populus tremuloides-Abies lasiocarpa / Pedicularis racemosa C.T.	Mountains of western Wyoming	Cool moist	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides* *P. menziesii*	*P. racemosa* *A. cordifolia* *S. oreophilus*	Youngblood and Mueggler 1981
Populus tremuloides / Ranunculus alismaefolius C.T.	Mountains of western Wyoming	Cool moist to wet	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides*	*R. alismaefolius* *Carex microptera* *Trifolium longipes*	Youngblood and Mueggler 1981
Populus tremuloides-Abies lasiocarpa / Rudbeckia occidentalis C.T., *P. tremuloides / R. occidentalis* C.T.	Mountains of southeastern Idaho and western Wyoming	Cool moist to well-drained	Seral to *A. lasiocarpa*	*A. lasiocarpa* *P. tremuloides*	*R. occidentalis* *T. longipes* *Nemophila breviflora* *Melica spectabilis*	Mueggler and Campbell 1982 Youngblood and Mueggler 1981

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
			***Thuja plicata* series**			
Thuja plicata / *Oplopanax horridum* H.T.	Mountains of northern Idaho, eastern Washington and Oregon	Cool moist	Seral to *T. plicata* *T. heterophylla*	*T. plicata* *T. heterophylla* *L. occidentalis* *Pinus monticola* *A. grandis*	*O. horridum* *Athyrium felix-femina* *Dryopteris dilatata*	Cooper et al. 1983 Daubenmire and Daubenmire 196
Thuja plicata / *Pachistima myrsinites* H.T.	Mountains of northern Idaho, eastern Washington and Oregon	Warm dry to well-drained	Seral to *T. plicata*	*T. plicata* *P. monticola* *L. occidentalis* *P. menziesii* *P. contorta* *A. grandis*	*P. myrsinites* *A. glabrum* *G. triflorum*	Daubenmire and Daubenmire 196
Thuja plicata / *Athyrium felix-femina* H.T.	Mountains of northern Idaho, eastern Washington and Oregon	Cool wet	Seral to *T. plicata*	*T. plicata* *P. monticola* *A. grandis* *P. menziesii*	*A. felix-femina* *G. triflorum* *S. triangularis* *S. amplexifolius*	Cooper et al. 1983 Daubenmire and Daubenmire 196
Thuja plicata / *Clintonia uniflora* H.T.	Mountains of northern Idaho and northwestern Montana	Cool to warm moist bottomlands	Seral to *T. plicata*	*T. plicata* *A. lasiocarpa* *A. grandis* *P. menziesii* *L. occidentalis* *P. contorta*	*A. nudicaulis* *C. uniflora* *M. ferruginea* *X. tenax*	Cooper et al. 1983 Pfister et al. 1977
			***Pseudotsuga menziesii* series**			
Pseudotsuga menziesii / *Pachistima myrsinites* H.T.	Mountains of west-central Colorado	Warm dry	Minor climax to *P. menziesii*	*P. menziesii* *P. contorta* *P. tremuloides*	*P. myrsinites* *S. oreophilus* *A. cordifolia* *B. repens* *V. myrtillus*	Hess and Wasser 1982
Pseudotsuga menziesii / *Holodiscus dumosus* H.T. (Scree Forest)	Mountains of New Mexico and southern Colorado	Warm dry to well-drained	Seral to *P. menziesii*	*P. menziesii* *A. lasiocarpa* *P. tremuloides* *P. strobiformis*	*H. dumosus* *Salix* spp. *S. oreophilus* *B. ciliatus*	DeVelice et al. 1984 Fitzhugh et al. 1984
			***Abies grandis* series**			
Abies grandis / *Linnaea borealis* H.T.	Mountains of Montana and Idaho	Cool moist to well-drained	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. monticola* *P. ponderosa* *P. menziesii* *L. occidentalis*	*L. borealis* *Disporum hookeri* *A. cordifolia* *V. globulare*	Pfister et al. 1977 Steele et al. 1981
Abies grandis / *Pachistima myrsinites* H.T.	Mountains of northern Idaho, eastern Washington and Oregon	Warm well-drained	Seral to *A. grandis*	*A. grandis* *P. menziesii* *L. occidentalis* *P. contorta* *P. monticola*	*P. myrsinites* *G. triflorum* *S. stellata* *T. occidentale*	Daubenmire and Daubenmire 196
Abies grandis / *Vaccinium caespitosum* H.T.	Mountains of central Idaho	Cool well-drained	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. menziesii* *L. occidentalis*	*V. caespitosum* *F. virginiana* *C. rubescens*	Steele et al. 1981
Abies grandis / *Vaccinium globulare* H.T.	Mountains of central Idaho	Cool well-drained	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. contorta* *P. menziesii*	*V. globulare*	Steele et al. 1983

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
bies grandis / Xerophyllum tenax H.T.	Mountains of northern Idaho	Cool dry	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. ponderosa* *P. contorta* *P. menziesii*	*X. tenax* *V. globulare*	Cooper et al. 1983
bies grandis / Clintonia uniflora H.T.	Mountains of western Montana, northern and central Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. menziesii* *P. ponderosa* *P. contorta* *L. occidentalis*	*C. uniflora* *L. borealis* *Adenocaulon bicolor* *X. tenax* *M. ferruginea*	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981
bies grandis / Coptis occidentalis H.T.	Mountains of northern Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *A. lasiocarpa* *P. contorta* *P. menziesii* *P. ponderosa*	*C. occidentalis* *V. globulare* *X. tenax* *S. albus*	Cooper et al. 1983
bies grandis / Senecio triangularis H.T.	Mountains of northern Idaho	Warm moist	Seral to *A. grandis*	*A. grandis* *L. occidentalis* *A. lasiocarpa*	*S. triangularis* *A. felix-femina* *Trautretteria caroliniensis*	Cooper et al. 1983
bies concolor / Acer glabrum H.T.	Mountains of northern New Mexico and Arizona	Warm dry	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. pungens* *P. tremuloides* *P. strobiformis* *A. lasiocarpa* *P. ponderosa*	*A. glabrum* *A. alnifolia* *B. repens* *P. myrsinites*	DeVelice et al. 1984 Fitzhugh et al. 1984
***Abies concolor* series**						
bies concolor / Robinia neomexicana H.T. *A. concolor-Pseudotsuga menziesii / R. neomexicana* H.T.]	Mountains of New Mexico and Arizona	Warm dry	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. ponderosa* *P. menziesii* *P. tremuloides* *P. strobiformis*	*S. oreophilis* *R. neomexicana* *Quercus gambelii*	Fitzhugh et al. 1984 Moir and Ludwig 1979
bies concolor / Vaccinium myrtillus H.T.	Mountains of northern New Mexico and southern Colorado	Cool dry	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. pungens* *A. lasiocarpa* *P. tremuloides*	*V. myrtillus* *A. glabrum* *A. uva-ursi* *P. myrsinites* *R. parviflorus*	DeVelice et al. 1984
bies concolor / Erigeron eximius H.T.	Mountains of northern New Mexico	Cool moist	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. pungens* *P. tremuloides*	*E. eximius* (*E. superbus*) *C. foenea* *Lathyrus* spp. *Fragaria* spp.	DeVelice et al. 1984
bies concolor / Osmorhiza chilensis H.T.	Wasatch Mountains, Utah	Warm moist	Seral to *A. concolor*	*A. concolor* *P. menziesii* *A. grandis* *P. tremuloides*	*O. chilensis* *P. malvaceus* *P. myrsinites* *P. virginiana*	Mauk and Henderson 1984
suga heterophylla / Clintonia uniflora H.T.	Mountains of northern Idaho and northwestern Montana	Warm moist	Seral to *T. heterophylla* *T. plicata*	*T. heterophylla* *T. plicata* *P. monticola* *P. contorta* *P. menziesii* *L. occidentalis*	*C. uniflora* *A. nudicaulis* *X. tenax* *M. ferruginea*	Cooper et al. 1983 Pfister et al. 1977

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
***Tsuga heterophylla* series**						
Tsuga heterophylla / Gymnocarpium dryopteris H.T.	Mountains of northern Idaho	Warm moist	Seral to *T. heterophylla*	*T. heterophylla* *A. grandis* *L. occidentalis* *T. plicata* *P. monticola*	*G. dryopteris* *P. myrsinites*	Cooper et al. 1983
***Tsuga mertensiana* series**						
Tsuga mertensiana / Menziesia ferruginea H.T.	Mountains of northern Idaho, western Washington, and southern British Columbia to central Oregon	Cool moist	Seral to *T. mertensiana*	*T. mertensiana* *A. lasiocarpa* *P. contorta* *L. occidentalis*	*M. ferruginea* *X. tenax* *R. albiflorum* *L. hitchcockii*	Cooper et al. 1983 Daubenmire and Daubenmire 196 Pfister et al. 1977
Tsuga mertensiana Xerophyllum tenax H.T.	Mountains of northern Idaho and northwestern Montana	Warm dry	Seral to *T. mertensiana* *A. lasiocarpa*	*A. lasiocarpa* *P. menziesii* *T. mertensiana* *P. monticola* *P. contorta* *P. albicaulis* *L. occidentalis*	*X. tenax* *V. membranaceum* *V. globulare*	Cooper et al. 1983 Daubenmire and Daubenmire 196 Pfister et al. 1977
Tsuga mertensiana / Luzula hitchcockii H.T.	Mountains of Montana west of Continental Divide, central and southern Idaho, and northwestern Wyoming	Cool well-drained	Seral to *T. mertensiana* *A. lasiocarpa*	*A. lasiocarpa* *T. mertensiana* *P. contorta* *P. albicaulis*	*L. hitchcockii* *V. scoparium* *X. tenax* *A. latifolia*	Pfister et al. 1977
Tsuga mertensiana / Clintonia uniflora H.T.	Mountains of northern Idaho	Warm moist	Seral to *T. mertensiana*	*T. mertensiana* *A. lasiocarpa* *P. menziesii* *L. occidentalis* *P. monticola* *P. contorta*	*C. uniflora* *X. tenax* *M. ferruginea*	Cooper et al. 1983
Tsuga mertensiana / Streptopus amplexifolius H.T.	Mountains of northern Idaho	Warm moist	Seral to *T. mertensiana*	*T. mertensiana* *P. menziesii* *L. occidentalis* *A. lasiocarpa*	*S. amplexifolius* *M. ferruginea* *S. triangularis* *T. caroliniensis*	Cooper et al. 1983
***Pinus flexilis* series**						
Pinus flexilis / Arctostaphylos uva-ursi H.T.	Mountains of northern New Mexico and southern Colorado	Warm dry	Minor climax to *P. flexilis*	*P. flexilis* *P. menziesii* (minor climax)	*A. uva-ursi* *J. communis*	DeVelice et al. 1984
Pinus flexilis / Calamagrostis purpurascens H.T.	Mountains of Colorado, east of the Continental Divide	Cool dry	Minor climax to *P. flexilis*	*P. flexilis*	*C. purpurascens* *Carex* spp. *T. spicatum*	Hess 1981
Pinus flexilis / Trifolium dasyphyllum H.T.	Mountains of north-central Colorado	Cool dry	Minor climax to *P. flexilis*	*P. flexilis*	*T. dasyphyllum* *C. purpurascens* *C. foenea*	Hess 1981

Table A7.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *P. engelmannii*	Principal tree associates	Principal understory species	Authority
			***Pinus aristata* series**			
Pinus aristata / *Festuca arizonica* H.T.	Mountains of southern Colorado	Warm dry	Co-climax with *P. aristata*	*P. aristata* (may form pure stands on drier sites)	*F. arizonica* *F. thurberi*	DeVelice et al. 1984
Pinus aristata / *Festuca thurberi* H.T.	San Juan and Sangre de Cristo Mountains, Colorado	Cool dry	Co-climax with *P. aristata*	*P. aristata*	*F. thurberi* *R. montigenum* *P. delicatum* (P. pulcherrimum)	DeVelice et al. 1984
Pinus aristata / *Trifolium dasyphyllum* H.T.	Mountains of north-central Colorado	Cool dry	Minor climax to *P. aristata*	*P. aristata*	*T. dasyphyllum* *C. purpurascens* *P. delicatum* (P. pulcherrimum)	Hess 1981
			***Pinus albicaulis* series**			
Pinus albicaulis / *Vaccinium scoparium* H.T.	Mountains of northwestern Wyoming	Cool dry	Minor climax to *P. albicaulis* *P. contorta*	*P. albicaulis* *P. contorta* *A. lasiocarpa*	*V. scoparium* *C. rossii* *A. cordifolia*	Steele et al. 1983
Pinus albicaulis / *Carex rossii* H.T.	Mountains of northwestern Wyoming	Cool dry	Minor climax to *P. albicaulis*	*P. albicaulis* *A. lasiocarpa* *P. contorta*	*C. rossii*	Steele et al. 1983
Pinus albicaulis-*Abies lasiocarpa* H.T.	Mountains of Montana and northern Idaho	Cool dry	Minor climax to *A. lasiocarpa* *P. albicaulis*	*A. lasiocarpa* *P. albicaulis*	*V. scoparium* *A. latifolia* *Hieracium gracile*	Cooper et al. 1983 Pfister et al. 1977
			***Larix lyallii* series**			
Larix lyallii-*Abies lasiocarpa* H.T.	Mountains of Montana west of Continental Divide, and northern Idaho	Cool dry	Minor climax to *L. lyallii* *A. lasiocarpa*	*A. lasiocarpa* *L. lyallii* *P. albicaulis*	*P. empetriformis* *V. scoparium* *L. hitchcockii*	Cooper et al. 1983 Pfister et al. 1977

Table A8.—Habitat types, community types, and plant communities in which *Abies lasiocarpa* is a major climax, co-climax, minor climax, or seral.

Habitat type, community type, or plant community	**Location**	**Site**	**Successional status of *A. lasiocarpa***	**Principal associates**	**Principal understory species**	**Authority**
			***Abies lasiocarpa* series**			
Abies lasiocarpa / Acer glabrum H.T.	Mountains of central and southern Idaho, northern and central Utah, and northwestern Wyoming; mountains of north-central and northwestern New Mexico	Warm moist	Climax	*Picea engelmannii* *Pseudotsuga menziesii* *Pinus contorta* *Populus tremuloides* *Abies concolor* *Picea pungens* *Pinus flexilis*	*A. glabrum* *Thalictrum occidentale* *Thalictrum fendleri* *Osmorhiza chilensis* *Arnica cordifolia* *Berberis repens* *Bromus ciliatus*	Alexander et al. 1984c Mauk and Hende son 1984 Steele et al. 1981 1983 Youngblood 1984
Abies lasiocarpa / Alnus sinuata H.T.	Mountains of northern Montana and central Idaho	Cool moist	Climax	*P. engelmannii* *P. menziesii* *P. contorta* *Larix occidentalis*	*A. sinuata* *Xerophyllum tenax* *Vaccinium scoparium* *Vaccinium globulare*	Pfister et al. 197 Steele et al. 1981
Abies lasiocarpa / Berberis repens H.T.	Mountains of Utah, northwestern Wyoming, and southeastern Idaho	Warm to cool well-drained	Climax	*P. engelmannii* (minor climax) *P. contorta* *P. pungens* *P. menziesii* *P. flexilis* *A. concolor* *P. tremuloides*	*B. repens* *Ribes montigenum* *Carex geyeri* *Pachistima myrsinites* *Symphoricarpos oreophilus*	Mauk and Hende son 1984 Pfister 1972 Steele et al. 198 Youngblood 1984
Abies lasiocarpa / Clematis pseudoalpina H.T.	Mountains of Montana east of Continental Divide	Warm dry	Climax	*P. engelmannii* *P. flexilis* *P. contorta* *P. menziesii* *Pinus albicaulis*	*C. pseudoalpina* *Clematis tenuiloba*	Pfister et al. 197
Abies lasiocarpa / Juniperus communis H.T.	Mountains of central Idaho, northwestern Wyoming, Utah, northern Arizona, and New Mexico	Warm to cold dry	Climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta* *P. tremuloides* *A. concolor* *P. pungens* (UT) *Pinus longaeva* (UT)	*J. communis* *Pyrola secunda* *Shepherdia canadensis* *A. cordifolia* *S. oreophilus* *Rosa woodsii*	Mauk and Hende son 1984 Moir and Ludwig 1979 Steele et al. 1981 1983 Youngblood 1984
Abies lasiocarpa / Linnaea borealis H.T., *A. lasiocarpa-Picea engelmannii /L. borealis* P.C. (CO)	Mountains of Montana, central and southern Idaho, northwestern Wyoming, and central Colorado	Cool moist to well-drained	Climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. menziesii* *P. tremuloides* *L. occidentalis* *Pinus ponderosa*	*L. borealis* *V. scoparium* *Calamagrostis rubescens* *A. cordifolia*	Pfister et al. 197 Steele et al. 1981 1983 Steen and Dix 19
Abies lasiocarpa / Menziesia ferruginea H.T.	Mountains of southeastern Washington, eastern Oregon, Montana, Idaho, and northwestern Wyoming	Cool moist	Climax	*P. engelmannii* *P. contorta* *P. menziesii* *L. occidentalis* *Pinus monticola* *P. albicaulis*	*M. ferruginea* *Rhododendron albiflorum* *Ledum glandulosum* *V. globulare* *Arnica latifolia* *X. tenax*	Cooper et al. 198 Daubenmire and Daubenmire 19 Pfister et al. 197 Steele et al. 1981 1983

Table A8.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / Oplopanax horridum H.T.	Mountains of northern Montana	Cool moist-wet	Co-climax with *P. engelmannii*	*P. engelmannii* *P. monticola* *P. menziesii* *L. occidentalis*	*O. horridum* *Taxus brevifolia*	Pfister et al. 1977
Abies lasiocarpa / Pachistima myrsinites H.T., *A. lasiocarpa-Picea engelmannii / P. myrsinites* H.T. (CO)	Mountains of Montana and Idaho south to southern Colorado	Warm dry to well-drained	Climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta* *P. monticola* *L. occidentalis* *P. tremuloides*	*P. myrsinites* *Clintonia uniflora* *Galium triflorum* *C. geyeri* *Erigeron* spp.	Daubenmire and Daubenmire 1968 Hess and Wasser 1982 Steen and Dix 1974
Abies lasiocarpa / Physocarpus malvaceus H.T.	Mountains of eastern Idaho, northwestern Wyoming, northern and central Utah	Warm moist	Climax	*P. engelmannii* *P. menziesii* *P. tremuloides* *A. concolor*	*P. malvaceus* *Symphoricarpos albus* *Spiraea betulifolia* *Amelanchier alnifolia* *Sorbus scopulina*	Mauk and Henderson 1984 Steel et al. 1983 Youngblood 1984
Abies lasiocarpa / Ribes montigenum H.T.	Mountains of southern Montana, Idaho, Utah, and northwestern Wyoming	Cool dry	Climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. tremuloides* *P. menziesii* *P. albicaulis*	*R. montigenum* *A. latifolia* *T. fendleri* *Antennaria microphylla* *Martensia arizonica*	Mauk and Henderson 1983 Pfister 1972 Pfister et al. 1977 Steel et al. 1981, 1983 Youngblood 1984
Abies lasiocarpa / Rubus parviflorus H.T.	Mimbres and Mogollon Mountains, New Mexico; San Juan Mountains, Colorado	Warm moist	Co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* (NM only) *A. concolor* (NM only) *P. tremuloides*	*R. parviflorus* *Vaccinium myrtillus* *A. glabrum* *P. myrsinites*	DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies lasiocarpa / Salix pseudolapponum H.T., *A. lasiocarpa-Picea engelmannii / S. glauca* H.T.	High mountains of Colorado	Cold wet	Co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. flexilis*	*S. pseudolapponum* *V. myrtillus* *Polemonium pulcherrimum* *Acomastylis rossii*	Hess 1981 Hess and Wasser 1982 Komarkova 1984
Abies lasiocarpa / Shepherdia canadensis H.T. (WY), *A. lasiocarpa-Picea engelmannii / S. canadensis* P.C. (CO)	Bighorn Mountains, Wyoming; mountains of central Colorado	Cool-warm dry	Co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. tremuloides* *P. menziesii*	*S. canadensis* *V. scoparium*	Hoffman and Alexander 1976 Steen and Dix 1974
Abies lasiocarpa / Spiraea betulifolia H.T.	Mountains of central and southern Idaho, and northwestern Wyoming	Warm dry	Climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis*	*S. betulifolia* *P. myrsinites* *C. rubescens*	Steele et al. 1981, 1983
Abies lasiocarpa / Symphoricarpos albus H.T.	Mountains of southeastern Idaho and northwestern Wyoming	Warm well-drained	Climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. tremuloides*	*S. albus* *A. alnifolia* *C. rubescens*	Steele et al. 1983

Table A8.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / Vaccinium caespitosum H.T.	Mountains of south-central Montana, central Idaho, northern and central Utah	Cool well-drained	Climax	*P. engelmannii* *P. contorta* *P. menziesii* *P. tremuloides*	*V. caespitosum* *L. borealis* *C. rubescens* *V. scoparium* *A. cordifolia*	Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981 Youngblood 1984
Abies lasiocarpa / Vaccinium globulare H.T.	Mountains of south-central Montana, central and southern Idaho, northern Utah, and northwestern Wyoming	Cool to moist well-drained	Climax	*P. engelmannii* *P. contorta* *P. menziesii* *P. tremuloides*	*V. globulare* *V. scoparium* *Lonicera utahensis* *P. myrsinites*	Mauk and Henderson 1984 Pfister et al. 1977 Steel et al. 1981, 1983
Abies lasiocarpa / Vaccinium membranaceum H.T.	Mountains of central Utah	Warm dry to well-drained	Climax	*P. engelmannii* *P. tremuloides*	*V. membranaceum* *P. myrsinites* *Carex rossii*	Youngblood 1984
Abies lasiocarpa / Vaccinium myrtillus H.T. [*A. lasiocarpa / V. myrtillus-Linnaea borealis* H.T.] [*A. lasiocarpa / V. myrtillus-Rubus parviflorus* H.T.] [*A. lasiocarpa /Vaccinium scoparium-L. borealis* H.T.]	Mogollon Plateau, Arizona; mountains of northern New Mexico and southern Colorado; LaSal Mountains, Utah	Cool moist to well-drained	Climax (AZ) co-climax with *P. engelmannii* (NM,CO,UT)	*P. engelmannii* *Pinus aristata* *P. tremuloides* *P. menziesii* *A. concolor* *P. flexilis* *P. pungens* *Pinus strobiformis*	*V. myrtillus* *Disporum trachycarpum* *Calamagrostis canadensis* *Polemonium flavum* *V. scoparium* *L. borealis* *R. parviflorus* *Erigeron eximius* (*E. superbus*)	Alexander et al. 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979 Youngblood 1984
Abies lasiocarpa / Vaccinium scoparium H.T., *A. lasiocarpa-Picea engelmannii / V. scoparium* H.T. [*P. engelmannii / V. scoparium* H.T.]	Mountains of Montana and Idaho south to Arizona and New Mexico	Cool dry	Climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *L. occidentalis* *P. tremuloides* *P. menziesii* *P. albicaulis*	*V. scoparium* *C. rubescens* *V. myrtillus* *A. cordifolia* *C. geyeri* *Erigeron superbus* (*E. eximius*) *L. borealis* *P. myrsinites* *Phyllodoce empetriformis*	Daubenmire and Daubenmire 196 Hess 1981 Hess and Wasser 1982 Hoffman and Alexander 1976, 198 1983 Komarkova 1984 Mauk and Henderson 1984 Moir and Ludwig 1979 Pfister 1972 Pfister et al. 1977 Steele et al. 1981, 1983 Steen and Dix 197 Wirsing and Alexander 1975
A. lasiocarpa-Pinus albicaulis / Vaccinium scoparium H.T.	Mountains of Montana east of Continental Divide	Cool dry	Co-climax with *P. albicaulis*	*P. albicaulis* *P. engelmannii* *P. contorta*	*V. scoparium* *X. tenax* *C. geyeri* *A. latifolia*	Pfister et al. 1977
Abies lasiocarpa / Xerophyllum tenax H.T.	Mountains of northern Idaho, eastern Washington, Idaho, Montana and northwestern Wyoming	Warm dry	Climax	*P. engelmannii* *P. albicaulis* *P. contorta* *P. menziesii* *P. ponderosa*	*X. tenax* *V. membranaceum* *V. scoparium* *V. globulare* *Luzula hitchcockii*	Cooper et al. 1983 Daubenmire and Daubenmire 196 Pfister et al. 1977 Steele et al. 1981, 1983

Table A8.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / Calamagrostis canadensis H.T., *A. lasiocarpa-Picea engelmannii / C. canadensis* H.T. [*P. engelmannii / C. canadensis* H.T.]	Mountains of central Montana, Idaho, northwestern Wyoming, northern Utah, north-central and western Colorado	Cool wet	Climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. tremuloides* *P. menziesii* (ID) *P. pungens* (UT)	*C. canadensis* *G. triflorum* *V. caespitosum* *L. glandulosum* *Senecio triangularis*	Cooper et al. 1983 Hess 1981 Komarkova 1984 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa / Calamagrostis rubescens H.T.	Mountains of Montana east of Continental Divide, central and southern Idaho, northern Utah, and northwestern Wyoming	Warm dry	Climax	*P. engelmannii* *P. contorta* *P. menziesii* *P. tremuloides*	*C. rubescens* *O. chilensis* *T. occidentale* *C. geyeri* *A. cordifolia* *P. myrsinites*	Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa / Luzula hitchcockii H.T.	Mountains of Montana west of Continental Divide, Idaho, and western Wyoming	Cool well-drained	Climax	*P. engelmannii* *P. albicaulis* *P. contorta*	*L. hitchcockii* *A. latifolia* *X. tenax* *A. cordifolia* *M. ferruginea* *V. scoparium*	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa / Carex geyeri H.T., *A. lasiocarpa-Picea engelmannii / C. geyeri* H.T. [*P. engelmannii / C. geyeri* H.T.]	Mountains of central Montana, central Idaho, southern Utah, Wyoming, and north-central and western Colorado	Warm to cool dry	Climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. menziesii* (MT,ID) *P. albicaulis* *P. tremuloides*	*C. geyeri* *S. oreophilus* *A. cordifolia* *Lupinus argenteus* *B. repens* *Lathyrus lanszwertii*	Hess 1981 Hess and Wasser 1982 Hoffman and Alexander 1976, 1983 Komarkova 1984 Pfister et al. 1977 Steele et al. 1981, 1983 Steen and Dix 1974 Wirsing and Alexander 1975 Youngblood 1984
Abies lasiocarpa / Carex rossii H.T.	Mountains of southern Idaho, Utah, and northwestern Wyoming	Warm dry	Climax	*P. engelmannii* *P. contorta* *P. tremuloides* *P. menziesii*	*C. rossii* *A. cordifolia* *Astragalus miser* *R. woodsii*	Steele et al. 1983 Youngblood 1984
Abies lasiocarpa / Pinus albicaulis H.T.	Mountains of northern Idaho and eastern Washington	Cool dry	Co-climax with *P. albicaulis*	*P. albicaulis*	*V. scoparium* *X. tenax* *C. geyeri* *Luzula glabrata*	Daubenmire and Daubenmire 1968
Abies lasiocarpa / Aconitum columbianum H.T.	Mountains of central and southern Utah	Cool moist	Climax	*P. engelmannii* *P. menziesii* *P. tremuloides* *A. concolor*	*A. columbianum* *Actaea rubra* *A. cordifolia* *B. ciliatus*	Youngblood 1984
Abies lasiocarpa / Actaea rubra H.T.	Mountains of central Idaho, northern Utah, and northwestern Wyoming	Warm moist	Co-climax with *P. engelmannii*	*P. engelmannii* *P. pungens* *P. menziesii* *P. contorta* *P. tremuloides*	*A. rubra* *O. chilensis* *L. utahensis* *V. globulare*	Mauk and Henderson 1984 Steele et al. 1983

Table A8.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / Arnica cordifolia H.T.	Mountains of Montana east of Continental Divide, central Idaho, northwestern and north-central Wyoming, and western Colorado	Cool well-drained	Climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. albicaulis* *P. menziesii* *P. tremuloides*	*A. cordifolia* *P. secunda* *A. miser* *Fragaria virginiana*	Hoffman and Alexander 1976 Komarkova 1984 Pfister et al. 1977 Steele et al. 1981, 1983
Abies lasiocarpa / Arnica latifolia H.T.	Mountains of southern Idaho, northern Utah, and northwestern Wyoming	Cool dry	Co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. tremuloides* *P. menziesii* *P. albicaulis*	*A. latifolia* *Aster engelmannii* *Pedicularis racemosa*	Steele et al. 1983
Abies lasiocarpa / Caltha biflora H.T.	Mountains of central Idaho	Cool wet	Co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta*	*C. biflora* *Lonicera involucrata* *Pedicularis bracteosa* *Dodecatheon jeffreyi*	Steele et al. 1981
Abies lasiocarpa-Picea engelmannii / Cardamine cordifolia P.C. [*A. lasiocarpa / Mertensia ciliata* H.T.]	Mountains of central and southern Colorado	Cool wet	Co-climax with *P. engelmannii*	*P. engelmannii* *P. tremuloides*	*C. cordifolia* *M. ciliata* *Mitella pentandra* *Carex bella*	DeVelice et al. 1984 Steen and Dix 197
Abies lasiocarpa / Clintonia uniflora H.T.	Mountains of northwestern Montana, northern and central Idaho	Warm moist to dry	Climax	*P. engelmannii* *P. contorta* *P. menziesii* *L. occidentalis* *P. monticola* *Abies grandis* *P. ponderosa*	*C. uniflora* *M. ferruginea* *V. caespitosum* *Aralia nudicaulis* *X. tenax*	Cooper et al. 1983 Pfister et al. 1977 Steele et al. 1981
Abies lasiocarpa / Coptis occidentalis H.T.	Mountains of central and northern Idaho	Warm moist	Climax	*P. engelmannii* *P. menziesii* *P. contorta* *L. occidentalis* *A. grandis*	*C. occidentalis* *X. tenax* *V. globulare* *M. ferruginea*	Cooper et al. 1983 Steele et al. 1981
Abies lasiocarpa / Erigeron superbus (*E. eximius*) H.T.	Mountains of southwestern Colorado, northern New Mexico, and Arizona	Cool dry	Co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *A. concolor* *P. ponderosa* *P. strobiformis* *P. tremuloides* *P. pungens*	*E. superbus* (*E. eximius*) *Geranium richardsonii* *Lathyrus arizonicus* *L. involucrata* *A. cordifolia* *B. repens*	Alexander et al. 1984c DeVelice et al. 1984 Fitzhugh et al. 1984 Moir and Ludwig 1979
Abies lasiocarpa / Galium triflorum H.T.	Mountains of northern Montana	Warm moist	Climax	*P. engelmannii* *P. contorta* *P. menziesii* *L. occidentalis*	*G. triflorum* *A. rubra* *Streptopus amplexifolius*	Pfister et al. 1977

Table A8.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
bies lasiocarpa / Lathyrus arizonicus H.T. *A. lasiocarpa-Pinus strobiformis / L. arizonicus* H.T.]	San Francisco Peaks, Arizona; Mogollon Mountains, New Mexico	Cool dry	Climax	*P. menziesii* *P. tremuloides* *P. strobiformis*	*L. arizonicus* *G. richardsonii* *Smilacina stellata* *A. glabrum* *S. oreophilus* *Vicia americana*	Fitzhugh et al. 1984 Moir and Ludwig 1979
bies lasiocarpa-Picea engelmannii / Lupinus argenteus P.C.	Mountains of central and southern Colorado	Warm well-drained	Co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* (long-lived seral)	*L. argenteus* *V. scoparium*	Steen and Dix 1974
bies lasiocarpa / Osmorhiza chilensis H.T.	Mountains of southern Idaho and northern Utah	Warm moist to well-drained	Climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. tremuloides*	*O. chilensis* *C. rossii* *B. repens* *P. myrsinites*	Mauk and Henderson 1984 Steele et al. 1983
Abies lasiocarpa / Pedicularis racemosa H.T.	Mountains of southeastern Idaho, northwestern Wyoming, and northern Utah	Warm dry	Climax	*P. engelmannii* *P. contorta* *P. menziesii* *P. tremuloides*	*P. racemosa* *A. cordifolia* *S. oreophilus*	Mauk and Henderson 1984 Steele et al. 1983
Abies lasiocarpa / Polemonium delicatum H.T., *A. lasiocarpa-Picea engelmannii / P. delicatum* P.C.	Mountains of Colorado	Cool dry	Co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. tremuloides*	*P. delicatum* (*P. pulcherrimum*) *Osmorhiza obtusa* *Vaccinium* spp.	Komarkova 1984 Steen and Dix 1974
Abies lasiocarpa / Saxifraga bronchialis H.T. (Scree Forest)	Mogollon Mountains, Sangre de Cristo Mountains, northern New Mexico and southern Colorado	Warm dry	Climax	*P. menziesii* *P. strobiformis*	*S. bronchialis* *S. oreophilus* *J. communis* *Holodiscus dumosus* *L. involucrata* *Erigeron vetensis*	DeVelice et al. 1984 Fitzhugh et al. 1984
Abies lasiocarpa / Senecio sanguisorboides H.T.	Sacramento Mountains, southern New Mexico	Cool dry to well-drained	Co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. tremuloides*	*S. sanguisorboides* *R. montigenum* *Ribes wolfii*	Alexander et al. 1984a Moir and Ludwig 1979
Abies lasiocarpa / Senecio triangularis H.T., *A. lasiocarpa-Picea engelmannii / S. triangularis* H.T. [*P. engelmannii / S. triangularis* H.T.]	Mountains of north-central and western Colorado	Cool wet stream bottoms	Co-climax with *P. engelmannii*	*P. engelmannii*	*S. triangularis* *C. cordifolia* *Equisetum arvense* *M. ciliata*	Hess 1981 Komarkova 1984
Abies lasiocarpa / Streptopus amplexifolius H.T.	Mountains of Idaho and northwestern Utah	Warm moist to wet	Climax	*P. engelmannii* *P. contorta*	*S. amplexifolius* *S. triangularis* *Ligusticum canbyi* *Ribes lacustre*	Cooper et al. 1983 Steele et al. 1981, 1983

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
Abies lasiocarpa / Thalictrum occidentale H.T.	Mountains of southeastern Idaho and northwestern Wyoming	Warm well-drained	Climax	*P. engelmannii* *P. menziesii* *P. contorta* *P. tremuloides*	*T. occidentale* *O. chilensis* *A. cordifolia*	Steele et al. 1983
Abies lasiocarpa / Moss spp. H.T., *A. lasiocarpa-Picea engelmannii /* Moss spp. P.C.	Mountains of central and southwestern Colorado and northern New Mexico	Cool dry to well-drained	Co-climax with *P. engelmannii*	*P. engelmannii* *P. aristata* *P. tremuloides* *P. contorta* (CO) *P. menziesii* (NM)	Moss spp. *V. caespitosum* *Rosa* spp.	DeVelice et al. 1984 Komarkova 1984 Steen and Dix 19
			***Picea engelmannii* series**			
Picea engelmannii / Acer glabrum H.T.	Sacramento Mountains, New Mexico; Chiricahua Mountains, Arizona	Warm moist	Minor climax to *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. tremuloides*	*A. glabrum* *B. ciliatus* *Viola canadensis* *S. stellata*	Alexander et al. 1984a Moir and Ludwig 1979
Picea engelmannii / Physocarpus malvaceus H.T.	Mountains of south-central Montana	Warm moist	Minor climax to *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta*	*P. malvaceus* *S. albus* *S. betulifolia*	Pfister et al. 1977
Picea engelmannii / Vaccinium myrtillus H.T. [*P. engelmannii / V. myrtillus-Polemonium pulcherrimum* H.T.] [*P. engelmannii / Vaccinium scoparium-P. delicatum* H.T.]	Sangre de Cristo Mountains, southern Colorado and northern New Mexico	Cool dry	Minor climax to *P. engelmannii*	*P. engelmannii* *P. tremuloides* *P. aristata*	*V. myrtillus* *P. delicatum* (*P. pulcherrimum*) *Senecio* spp. *Deschampsia caespitosa* *Poa reflexa*	DeVelice et al. 1984 Moir and Ludwig 1979
Picea engelmannii / Vaccinium scoparium H.T.	Mountains of northwestern Wyoming	Cool dry	Minor climax to *P. engelmannii*	*P. engelmannii* *P. contorta* *P. flexilis* *P. albicaulis*	*V. scoparium* *A. cordifolia* *Antennaria* spp. *Lupinus* spp.	Steele et al. 1983
Picea engelmannii / Elymus triticoides H.T.	Capitan Mountains, New Mexico	Cool dry to well-drained	Minor climax to or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. tremuloides*	*E. triticoides* *A. glabrum* *Jamesia americana*	Alexander et al. 1984a Moir and Ludwig 1979
Picea engelmannii / Carex disperma H.T.	Mountains of central and southern Idaho, and northwestern Wyoming	Cool moist	Minor climax to *P. engelmannii*	*P. engelmannii* *P. contorta* *P. pungens*	*C. disperma* *P. secunda* *G. triflorum*	Steele et al. 1981 1983
Picea engelmannii / Caltha leptosepala H.T.	Mountains of northwestern Wyoming and east-central Idaho	Warm moist	Minor climax to *P. engelmannii*	*P. engelmannii* *P. contorta* *P. albicaulis*	*C. leptosepala* *Trollius taxus*	Steele et al. 1983

able A8.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
cea engelmannii / Equisetum arvense H.T.	Mountains of southern Montana, northwestern Wyoming, central Idaho, and northern Utah	Warm to cool, wet	Minor climax to *P. engelmannii*	*P. engelmannii* *P. contorta* *P. pungens*	*E. arvense* *S. amplexifolius* *S. triangularis* *Luzula parviflora*	Mauk and Henderson 1984 Steele et al. 1981, 1983
icea engelmannii / Galium trifolium H.T.	Mountains of central Idaho and northwestern Wyoming	Cool moist	Minor climax to *P. engelmannii*	*P. engelmannii* *P. contorta* *A. menziesii* *P. pungens*	*G. trifolium* *A. rubra* *S. stellata* *S. amplexifolius*	Steele et al. 1981, 1983
icea engelmannii / Saxifraga bronchialis H.T. (Scree Forest)	Mountains of northern New Mexico and southern Colorado	Warm dry	Minor climax to *P. engelmannii*	*P. engelmannii*	*S. bronchialis* *J. communis*	DeVelice et al. 1984
icea engelmannii / Senecio cardamine H.T.	Blue Mountains, Arizona	Cool moist	Seral or minor climax to *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. pungens* *P. ponderosa* *P. strobiformis* *A. concolor* *P. tremuloides*	*S. cardamine* *Fragaria ovalis* *G. richardsonii* *V. canadensis*	Fitzhugh et al. 1984
icea engelmannii / Trifolium dasyphyllum H.T.	Mountains of north-central Colorado	Cold moist	Minor climax to or co-climax with *P. engelmannii*	*P. engelmannii* *P. tremuloides* *P. flexilis*	*T. dasyphyllum* *Pyrola chlorantha* *Sedum lanceolatum*	Hess 1981
icea engelmannii / Moss spp. H.T.	Mountains of southwestern Colorado and northern New Mexico	Cool moist to well-drained	Co-climax with *P. engelmannii*	*P. engelmannii* *P. aristata* *P. tremuloides* *P. menziesii*	Moss spp. *Ribes* spp. *Vaccinium* spp. *L. arizonicus*	Alexander et al. 1984c Fitzhugh et al. 1984 Moir and Ludwig 1979
			***Picea pungens* series**			
icea pungens / Amelanchier alnifolia H.T.	Mountains of western and central Colorado	Warm moist	Minor climax to *P. pungens*	*P. pungens* *P. menziesii* *Populus angustifolia*	*A. alnifolia* *Cornus stolonifera* *C. geyeri* *Swida sericea*	Hess and Wasser 1982 Komarkova 1984
icea pungens / Linnaea borealis H.T. *P. pungens-Pseudotsuga menziesii / L. borealis* H.T.]	Mountains of northern New Mexico and southern Colorado	Cool well-drained	Minor climax to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *P. engelmannii* *A. concolor* *P. flexilis* *P. tremuloides*	*L. borealis* *P. myrsinites* *V. myrtillus*	DeVelice et al. 1984 Moir and Ludwig 1979

Table A8.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
Picea pungens / Erigeron eximius H.T. [*P. pungens-Picea engelmannii / E. superbus* H.T.]	White Mountains, Arizona	Cool dry	Minor climax to *P. engelmannii* *P. pungens*	*P. pungens* *P. engelmannii* *P. menziesii* *P. ponderosa* *P. strobiformis* *P. tremuloides* *P. flexilis* *P. concolor*	*E. superbus* (*E. eximius*) *Festuca arizonica* *Carex foenea* *F. virginiana*	Moir and Ludwig 1979
Picea pungens / Fragaria ovalis H.T.	Mountains of Arizona and New Mexico	Cool moist	Minor climax to *P. pungens* *P. menziesii*	*P. pungens* *P. menziesii* *P. engelmannii* *P. tremuloides* *A. concolor*	*F. ovalis* *Senecio cardamine* *E. eximius* (*E. superbus*) *Achillea millefolium* *C. foenea* *F. arizonica*	Fitzhugh et al. 1984
Picea pungens / Senecio cardamine H.T. [*P. pungens-Picea engelmannii / S. cardamine* H.T.]	White Mountains, Arizona	Cool moist	Co-climax with or minor climax to *P. engelmannii* *P. pungens*	*P. pungens* *P. engelmannii* *P. ponderosa* *P. menziesii* *P. strobiformis* *P. tremuloides* *A. concolor*	*S. cardamine* *Pteridium aquilinum* *Helenium hoopesii* *V. canadensis*	Moir and Ludwig 1979
***Pinus contorta* series and other *P. contorta* dominated vegetation**						
Pinus contorta / Arctostaphylos uva-ursi H.T. (UT); P.C. (CO)	Uinta Mountains, Utah; mountains of north-central Colorado	Warm dry	Minor climax to *P. contorta* (UT). Ultimate climax unknown (CO). Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. tremuloides*	*A. uva-ursi* *B. repens* *Sitanion hystrix*	Mauk and Hende son 1984 Steen and Dix 19
Pinus contorta / Juniperus communis H.T. (CO); C.T. (ID,WY)	Mountains of eastern Idaho, northwestern Wyoming, and central Colorado	Warm dry	Minor climax to *P. contorta* (CO). Ultimate climax unknown (ID,WY). Probably co-climax with *P. engelmannii* *P. menziesii*	*P. menziesii* *P. engelmannii* *P. tremuloides* *P. albicaulis* *P. contorta*	*J. communis* *A. uva-ursi* *S. canadensis* *A. cordifolia*	Hess 1981 Steele et al. 198
Pinus contorta / Linnaea borealis C.T. (MT,WY); P.C. (CO)	Mountains of Montana east of Continental Divide, northwestern Wyoming, and north-central Colorado	Cool moist to well-drained	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta*	*L. borealis* *V. scoparium* *V. globulare* *A. cordifolia* *C. rubescens*	Pfister et al. 197 Steele et al. 198 Steen and Dix 19
Pinus contorta / Pachistima myrsinites P.C.	Mountains of north-central Colorado	Warm dry to well-drained	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. tremuloides* *P. contorta*	*P. myrsinites* *V. scoparium* *J. communis* *L. borealis*	Steen and Dix 19

able A8.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
us contorta / Purshia tridentata H.T.	Mountains of western Montana	Cool-warm dry to well-drained	Minor climax to *P. contorta*	*P. contorta* *P. engelmannii* *P. menziesii* *P. tremuloides*	*P. tridentata* *A. uva-ursi* *C. rossii* *Lupinus* spp.	Pfister et al. 1977
us contorta / Shepherdia canadensis C.T. (ID,WY); P.C. (CO)	Mountains of southeastern Idaho, northwestern Wyoming, and central Colorado	Cool-warm dry to well-drained	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. tremuloides* *P. menziesii* *P. contorta*	*S. canadensis* *A. cordifolia* *J. communis* *L. borealis* *A. uva-ursi*	Steele et al. 1983 Steen and Dix 1974
nus contorta / Spiraea betulifolia C.T.	Mountains of eastern Idaho and northwestern Wyoming	Warm dry	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta*	*S. betulifolia* *C. rubescens* *C. geyeri*	Steele et al. 1983
nus contorta / Vaccinium caespitosum C.T.	Mountains of south-central Montana, Idaho, and northern Utah	Cool well-drained	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta*	*V. caespitosum* *V. scoparium* *Festuca ovina* *L. borealis*	Cooper et al. 1983 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981
inus contorta / Vaccinium globulare C.T.	Mountains of southern Idaho, northwestern Wyoming, and northern Utah	Cool well-drained	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta*	*V. globulare* *L. utahensis* *V. scoparium* *C. rubescens*	Steele et al. 1983
inus contorta / Vaccinium scoparium C.T.; P.C. (CO)	Mountains of Montana, Idaho, northwestern Wyoming, and northern Utah; mountains of southern Wyoming and central Colorado	Cool to cold dry	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii* *P. menziesii*	*P. engelmannii* *P. menziesii* *P. contorta* *P. albicaulis* *P. flexilis* *A. grandis* *Tsuga heterophylla* *L. occidentalis*	*V. scoparium* *C. rubescens* *A. cordifolia* *L. argenteus* *B. repens* *C. geyeri*	Cooper et al. 1983 Mauk and Henderson 1984 Pfister et al. 1977 Steele et al. 1981, 1983 Steen and Dix 1974 Wirsing and Alexander 1975
inus contorta / Xerophyllum tenax C.T.	Mountains of northern Idaho	Warm dry	Ultimate climax unknown. *P. contorta* may be climax	*P. contorta* *P. engelmannii* *P. menziesii*	*X. tenax* *Vaccinium* spp.	Cooper et al. 1983
inus contorta / Calamagrostis canadensis C.T.	Uinta Mountains, Utah	Cool moist	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta*	*C. canadensis* *A. cordifolia* *J. communis* *Poa nervosa*	Mauk and Henderson 1984

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
Pinus contorta / Calamagrostis rubescens C.T.	Mountains of Montana, Idaho, northern Utah, and northwestern Wyoming	Warm dry	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. menziesii* *P. contorta* *L. occidentalis*	*C. rubescens* *V. scoparium* *C. geyeri* *A. cordifolia* *A. uva-ursi*	Pfister et al. 1977 Steele et al. 1983
Pinus contorta / Carex geyeri C.T. (ID,WY); P.C. (CO)	Mountains of central Idaho, northwestern and southern Wyoming, and north-central Colorado	Cool dry	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. menziesii* *P. albicaulis* *P. flexilis* *P. tremuloides*	*C. geyeri* *S. oreophilus* *A. cordifolia* *L. argenteus* *B. repens* *J. communis*	Hess 1981 Hess and Wasse 1982 Steele et al. 1981 1983 Steen and Dix 19 Wiring and Alexander 1975
Pinus contorta / Carex rossii C.T.	Mountains of northwestern Wyoming	Warm dry	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. albicaulis* *P. contorta* *P. tremuloides*	*C. rossii* *L. argenteus* *P. nervosa*	Steele et al. 1983
Pinus contorta / Arnica cordifolia C.T.	Mountains of eastern Idaho and northwestern Wyoming	Cool dry	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. albicaulis* *P. flexilis*	*A. cordifolia* *Antennaria racemosa* *A. miser* *P. secunda*	Steele et al. 1983
Pinus contorta / Lupinus argenteus P.C.	Mountains of central and southern Colorado	Warm dry to well-drained	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. tremuloides* *P. contorta*	*L. argenteus*	Steen and Dix 19
Pinus contorta / Lichen spp. P.C.	Mountains of central Colorado	Hot dry	Ultimate climax unknown. Probably co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta*	Lichen spp.	Steen and Dix 19
***Populus tremuloides* series and other *P. tremuloides* dominated vegetation**						
Populus tremuloides-Abies lasiocarpa / Berberis repens C.T., *P. tremuloides / B. repens* C.T.	Mountains of western Wyoming	Warm to cool. Well-drained	Climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. tremuloides*	*B. repens* *S. albus* *P. myrsinites*	Youngblood and Mueggler 1981
Populus tremuloides / Pachistima myrsinites C.T. (ID); P.C. (CO)	Mountains of southeastern Idaho, central and southwestern Colorado	Warm dry	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. tremuloides* *P. menziesii*	*P. myrsinites* *V. scoparium* *C. geyeri* *C. rubescens*	Mueggler and Campbell 1982 Steen and Dix 197

ble A8.—(continued)

bitat type, mmunity type, or ant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
pulus tremuloides- *Abies lasiocarpa* / *Prunus virginiana* C.T., *tremuloides* / *P. virginiana* C.T.	Mountains of western Wyoming	Warm dry	Climax or co-climax with *P. menziesii*	*P. menziesii* *P. contorta* *P. tremuloides*	*P. virginiana* *B. repens* *S. oreophilus* *R. woodsii*	Youngblood and Mueggler 1981
pulus tremuloides- *Abies lasiocarpa* / *Shepherdia canadensis* C.T., *tremuloides* / *S. canadensis* C.T.	Mountains of western Wyoming	Cool-dry to well-drained	Climax	*P. engelmannii* *P. contorta* *P. tremuloides* *P. flexilis*	*S. canadensis* *Geranium viscosissimum* *A. cordifolia* *R. woodsii* *T. fendleri*	Youngblood and Mueggler 1981
pulus tremuloides- *Abies lasiocarpa* / *Symphoricarpos oreophilus* C.T., *tremuloides* / *S. oreophilus* C.T.	Mountains of southeastern Idaho, northern Utah, and western Wyoming	Warm well-drained	Ultimate climax unknown. Probably climax or co-climax with *P. menziesii*	*P. menziesii* *A. concolor* *P. tremuloides*	*S. oreophilus* *P. virginiana* *B. repens* *Elymus glaucus* *C. rubescens*	Mauk and Henderson 1984 Mueggler and Campbell 1982 Steele et al. 1983 Youngblood and Mueggler 1981
pulus tremuloides- *Pseudotsuga menziesii* / *Symphoricarpos oreophilus* C.T., *tremuloides* / *S. oreophilus* C.T.	Mountains of southeastern Idaho	Warm dry	Ultimate climax unknown. Probably minor climax to *P. menziesii*	*P. menziesii* *P. contorta* *P. tremuloides*	*S. oreophilus* *C. rubescens* *Poa pratensis* *C. geyeri*	Mueggler and Campbell 1982
pulus tremuloides- *Pinus contorta* / *Calamagrostis rubescens* C.T., *tremuloides* / *C. rubescens* C.T.	Mountains of southeastern Idaho	Warm dry	Ultimate climax unknown. Probably climax or co-climax with *P. menziesii*	*P. menziesii* *P. contorta* *P. tremuloides*	*C. rubescens* *S. oreophilus* *P. myrsinites* *L. argenteus* *T. fendleri* *G. viscosissimum*	Mueggler and Campbell 1982
pulus tremuloides / *Elymus glaucus* P.C.	Mountains of central and southwestern Colorado	Warm moist to well-drained	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. contorta* *P. tremuloides*	*E. glaucus* *A. alnifolia* *Symphoricarpos* spp. *Ligusticum porteri*	Steen and Dix 1974
pulus tremuloides / *Festuca thurberi* P.C.	Mountains of southwestern Colorado	Warm dry	Ultimate climax unknown. Probably climax or co-climax with *P. engelmannii*	*P. engelmannii* *P. tremuloides* *P. menziesii* *P. contorta*	*F. thurberi* *B. repens* *S. oreophilus* *F. ovalis*	Steen and Dix 1974
pulus tremuloides / *Poa pratensis* C.T.	Mountains of southeastern Idaho	Warm dry	Ultimate climax unknown. Probably climax or co-climax with *P. menziesii*	*P. menziesii* *P. tremuloides*	*P. pratensis* *C. rubescens* *T. fendleri* *P. nervosa* *L. argenteus*	Mueggler and Campbell 1982

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
Populus tremuloides-Abies lasiocarpa / Arnica cordifolia C.T., *P. tremuloides / A. cordifolia* C.T.	Mountains of western Wyoming	Cool moist to well-drained	Climax	*P. contorta* *P. tremuloides*	*A. cordifolia* *S. oreophilus* *C. rossii* *O. chilensis* *P. nervosa*	Youngblood and Mueggler 1981
Populus tremuloides / Geranium viscosissimum C.T.	Mountains of southeastern Idaho	Warm dry	Climax	*P. tremuloides*	*G. viscosissimum* *Symphoricarpos* spp. *L. argenteus* *T. fendleri*	Mueggler and Campbell 1982
Populus tremuloides / Heracleum lanatum C.T.	Mountains of western Wyoming	Warm moist	Climax	*P. engelmannii* *P. contorta* *P. tremuloides*	*H. lanatum* *P. bracteosa* *T. fendleri* *E. glaucus*	Youngblood and Mueggler 1981
Populus tremuloides-Abies lasiocarpa / Ligusticum filicinum C.T., *P. tremuloides / L. filicinum* C.T.	Mountains of western Wyoming	Cool moist to well-drained	Climax	*P. engelmannii* *P. tremuloides*	*L. filicinum* *T. fendleri* *G. viscosissimum* *Osmorhiza occidentalis*	Youngblood and Mueggler 1981
Populus tremuloides-Abies lasiocarpa / Pedicularis racemosa C.T.	Mountains of western Wyoming	Cool moist	Climax	*P. engelmannii* *P. tremuloides*	*P. racemosa* *A. cordifolia* *S. oreophilus*	Youngblood and Mueggler 1981
Populus tremuloides / Ranunculus alismaefolius C.T.	Mountains of western Wyoming	Cool moist to wet	Climax	*P. engelmannii* *P. tremuloides*	*R. alismaefolius* *Carex microptera* *Trifolium longipes*	Youngblood and Mueggler 1981
Populus tremuloides-Abies lasiocarpa / Rudbeckia occidentalis C.T., *P. tremuloides / R. occidentalis* C.T.	Mountains of southeastern Idaho and western Wyoming	Cool moist to well-drained	Climax	*P. engelmannii* *P. tremuloides*	*R. occidentalis* *T. longipes* *Nemophila breviflora* *Melica spectabilis* *Symphoricarpos* spp.	Mueggler and Campbell 1982 Youngblood and Mueggler 1981
Populus tremuloides-Abies lasiocarpa / Thalictrum fendleri C.T.	Mountains of southeastern Idaho	Warm moist	Climax	*P. tremuloides* *P. flexilis*	*T. fendleri* *S. oreophilus* *G. viscosissimum* *O. chilensis*	Mueggler and Campbell 1982
***Pseudotsuga menziesii* series**						
Pseudotsuga menziesii / Holodiscus dumosus H.T. (Scree Forest)	Mountains of New Mexico and southern Colorado	Warm dry to well-drained	Seral to *P. menziesii*	*P. menziesii* *P. engelmannii* *P. tremuloides* *P. strobiformis*	*H. dumosus* *Salix* spp. *S. oreophilus* *B. ciliatus*	DeVelice et al. 1984 Fitzhugh et al. 1984
***Thuja plicata* series**						
Thuja plicata / Oplopanax horridum H.T.	Mountains of northwestern Montana	Warm wet to cool wet	Seral or minor climax to *T. plicata*	*T. plicata* *T. heterophylla* *T. mertensiana* *P. monticola*	*O. horridum* *Athyrium felix-femina* *Gymnocarpium dryopteris*	Pfister et al. 1977

Table A8.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
huja plicata / *Clintonia uniflora* H.T.	Mountains of northwestern Montana and northern Idaho	Cool to warm dry bottomlands	Seral or minor climax to *T. plicata*	*T. plicata* *A. grandis* *P. engelmannii* *P. menziesii* *L. occidentalis* *P. contorta*	*C. uniflora* *M. ferruginea* *A. nudicaulis* *X. tenax*	Cooper et al. 1983 Pfister et al. 1977
			***Abies grandis* series**			
bies grandis / *Acer glabrum* H.T.	Mountains of central Idaho	Warm moist	Minor climax to *A. grandis*	*A. grandis* *P. contorta* *P. menziesii*	*A. glabrum* *P. malvaceus*	Steele et al. 1981
bies grandis / *Linnaea borealis* H.T.	Mountains of central Montana	Cool moist to well-drained	Minor climax to *A. grandis*	*A. grandis* *P. contorta* *P. engelmannii* *P. monticola* *P. ponderosa* *P. menziesii* *L. occidentalis*	*L. borealis* *Adenocaulon bicolor* *Disporum hookeri*	Pfister et al. 1977
bies grandis / *Vaccinium caespitosum* H.T.	Mountains of central Idaho	Cool well-drained	Minor climax to *A. grandis*	*A. grandis* *P. engelmannii* *P. menziesii* *L. occidentalis*	*V. caespitosum* *F. virginiana* *C. rubescens*	Steele et al. 1981
bies grandis / *Vaccinium globulare* H.T.	Mountains of central Idaho	Cool well-drained	Minor climax to *A. grandis*	*A. grandis* *P. engelmannii* *P. menziesii* *P. contorta*	*V. globulare*	Steele et al. 1981
bies grandis / *Xerophyllum tenax* H.T.	Mountains of northern Idaho	Cool dry	Minor climax to *A. grandis*	*A. grandis* *P. engelmannii* *P. contorta* *P. ponderosa* *P. menziesii*	*X. tenax* *V. globulare*	Cooper et al. 1983
bies grandis / *Clintonia uniflora* H.T.	Mountains of west-central and northwestern Montana and northern Idaho	Warm moist	Minor climax to *A. grandis*	*A. grandis* *P. menziesii* *P. engelmannii* *L. occidentalis* *P. contorta* *P. ponderosa*	*C. uniflora* *L. borealis* *A. bicolor* *X. tenax* *M. ferruginea*	Cooper et al. 1983 Pfister et al. 1977
bies grandis / *Coptis occidentalis* H.T.	Mountains of northern Idaho	Warm moist	Minor climax to *A. grandis*	*A. grandis* *P. engelmannii* *L. occidentalis* *P. contorta* *P. menziesii* *P. ponderosa*	*C. occidentalis* *V. globulare* *X. tenax* *S. albus*	Cooper et al. 1983
bies grandis / *Senecio triangularis* H.T.	Mountains of northern Idaho	Warm moist	Minor climax to *A. grandis*	*A. grandis* *P. engelmannii* *L. occidentalis*	*S. triangularis* *A. felix-femina* *Trautvetteria caroliniensis*	Cooper et al. 1983

Table A8.—(continued)

Habitat type, community type, or plant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
			***Abies concolor* series**			
Abies concolor / Acer glabrum H.T.	Mountains of northern New Mexico	Warm moist	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. engelmannii* *P. ponderosa* *P. strobiformis* *P. tremuloides*	*A. glabrum* *J. communis* *B. repens* *H. dumosus* *H. hoopesii* *C. stolonifera*	Fitzhugh et al. 1984
Abies concolor / Vaccinium myrtillus H.T.	Mountains of northern New Mexico and southern Colorado	Cool dry	Minor climax to *A. concolor* *P. menziesii*	*A. concolor* *P. menziesii* *P. pungens* *P. engelmannii* *P. tremuloides*	*V. myrtillus* *A. uva-ursi* *P. myrsinites* *A. glabrum* *R. parviflorus*	DeVelice et al. 1984
			***Tsuga heterophylla* series**			
Tsuga heterophylla / Clintonia uniflora H.T.	Mountains of northwestern Montana and northern Idaho	Warm moist	Minor climax to *T. heterophylla* *T. plicata*	*T. heterophylla* *T. plicata* *P. monticola* *P. contorta* *P. menziesii* *L. occidentalis* *P. engelmannii*	*C. uniflora* *A. nudicaulis* *X. tenax* *M. ferruginea*	Cooper et al. 198 Pfister et al. 1977
			***Tsuga mertensiana* series**			
Tsuga mertensiana / Menziesia ferruginea H.T.	Mountains of northern Idaho and western Montana	Cool moist	Minor climax to *T. mertensiana*	*T. mertensiana* *P. engelmannii* *L. occidentalis* *P. contorta*	*M. ferruginea* *R. albiflorum* *X. tenax* *L. hitchcockii*	Cooper et al. 198 Daubenmire and Daubenmire 19 Pfister et al. 1977
Tsuga mertensiana / Xerophyllum tenax H.T.	Mountains of northern Idaho, northwestern Montana, and British Columbia south to central Oregon	Warm dry	Seral to or co-climax with *T. mertensiana*	*T. mertensiana* *P. contorta* *P. menziesii* *P. engelmannii* *P. albicaulis* *P. monticola* *L. occidentalis*	*X. tenax* *V. membranaceum* *V. globulare*	Cooper et al. 198 Daubenmire and Daubenmire 19 Pfister et al. 1977
Tsuga mertensiana / Luzula hitchcockii H.T.	Mountains of western Montana and northern Idaho	Cool well-drained	Co-climax with *T. mertensiana*	*T. mertensiana* *P. contorta* *P. albicaulis* *P. engelmannii*	*L. hitchcockii* *V. scoparium* *X. tenax* *A. latifolia*	Pfister et al. 1977
Tsuga mertensiana / Clintonia uniflora H.T.	Mountains of northern Idaho	Warm moist	Seral or minor climax to *T. mertensiana*	*T. mertensiana* *P. engelmannii* *P. menziesii* *P. contorta* *L. occidentalis*	*C. uniflora* *X. tenax* *M. ferruginea*	Cooper et al. 198
Tsuga mertensiana / Streptopus amplexifolius H.T.	Mountains of northern Idaho	Warm moist	Seral or minor climax to *T. mertensiana*	*T. mertensiana* *P. engelmannii* *P. menziesii* *L. occidentalis*	*S. amplexifolius* *S. triangularis* *T. caroliniensis* *M. ferruginea*	Cooper et al. 198

able A8.—(continued)

abitat type, ommunity type, or lant community	Location	Site	Successional status of *A. lasiocarpa*	Principal tree associates	Principal understory species	Authority
***Pinus albicaulis* series**						
nus albicaulis / Vaccinium scoparium H.T.	Mountains of northwestern Wyoming	Cool dry	Minor climax to *P. albicaulis* *P. contorta*	*P. albicaulis* *P. contorta* *P. engelmannii*	*V. scoparium* *A. cordifolia* *C. rossii*	Steele et al. 1983
nus albicaulis / Carex rossii H.T.	Mountains of northwestern Wyoming	Cool dry	Minor climax to *P. albicaulis*	*P. albicaulis* *P. contorta* *P. engelmannii* (minor climax)	*C. rossii*	Steele et al. 1983
nus albicaulis- Abies lasiocarpa H.T.	Mountains of northern Idaho and Montana	Cool dry	Co-climax with *P. albicaulis*	*P. albicaulis* *P. engelmannii*	*V. scoparium* *A. latifolia* *Hieracium gracile*	Cooper et al. 1983 Pfister et al. 1977
***Larix lyallii* series**						
rix lyallii- Abies lasiocarpa H.T.	Mountains of Montana west of Continental Divide, and northern Idaho	Cool dry	Co-climax with *L. lyallii*	*L. lyallii* *P. engelmannii* *P. albicaulis*	*P. empetriformis* *V. scoparium* *L. hitchcockii*	Cooper et al. 1983 Pfister et al. 1977

Alexander, Robert R. 1985. Major habitat types, community types, and plant communities in the Rocky Mountains. USDA Forest Service General Technical Report RM-123, 105 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Habitat types, community types and plant communities in the Rocky Mountains in which interior *Pinus ponderosa*, interior *Pseudotsuga menziesii*, interior *Abies concolor*, *Picea pungens*, *Populus tremuloides*, *Pinus contorta*, *Picea engelmannii*, and *Abies lasiocarpa* occur are tabulated. Included are the name, location, site, successional status, principal tree and understory associates, and the authority.

Keywords: Vegetation classification, habitat type, community type, plant community, *Pinus ponderosa*, *Pseudostuga menziesii*, *Picea pungens*, *Abies concolor*, *Populus tremuloides*, *Pinus contorta*, *Picea engelmannii*, *Abies lasiocarpa*.

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

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Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
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*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

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An Evaluation of Procedures Used to Predict Timber Growth and Harvest in the Range and Multiple Resource Interactions Sections of the 1980 RPA Assessment

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John E. Mitchell and James B. Pickens

Abstract

Interdisciplinary (ID) team estimates of wood growth and harvest used in the Range and Multiple Resource Interactions sections of the 1980 RPA Assessment were evaluated by checking for the presence of joint resource production estimates, examining data set documentation, and searching for logical and procedural errors. Apparent deficiencies in ID-team training and procedural documentation were found to limit the usefulness of the wood growth and harvest estimates.

Acknowledgment

Andrew Vigil organized and prepared large amounts of written information for analysis in this study.

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An Evaluation of Procedures Used to Predict Timber Growth and Harvest in the Range and Multiple Resource Interactions Sections of the 1980 RPA Assessment

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Contents

Page
Management Implications 1
Introduction 1
Description of ID-Team Procedures 1
Methods 2
Results and Discussion 6
  Data Set and Procedural Documentation 7
  Logical and Procedural Errors 7
Conclusions 9
Literature Cited 10

An Evaluation of Procedures Used to Predict Timber Growth and Harvest in the Range and Multiple Resource Interactions Sections of the 1980 RPA Assessment

John E. Mitchell and James B. Pickens

Management Implications

The data set used by the Range and Multiple Resource nteractions chapters of the 1980 RPA Assessment (Forest ervice 1980) was developed by interdisciplinary (ID) eams to serve as input to an optimization model. To date, t remains the only existing multiresource data set vailable encompassing all range and forest lands in the 8 conterminous states of the U.S. This factor has led to onsiderable interest, both within the Forest Service and rom other groups, in using it for applications other than he linear programming model for which it was developed.

This paper evaluates the completeness and eproducibility of the wood growth and yield components f the data set. In addition, some characteristics of the ata generation process, especially with reference to the ature of periodic outputs, such as timber harvest, are xplained to help ascertain the appropriateness of the ata for different applications, and indicate ransformations that may be necessary.

The evaluation of the wood growth and yield estimates alls attention to large differences in the quality and eproducibility of estimates by different ID teams. These ifferences indicate that training of ID teams and their eaders prior to data generation requires additional mphasis.

Introduction

During the past decade, Congress passed laws requirng federal agencies to make recurring assessments of resent and projected resources derived from our Naion's forests, rangeland, and agricultural land. The laws ssigning assessment responsibilities to the USDA Forest ervice are the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA)[2] as amended by the ational Forest Management Act of 1976 (NFMA).[3]

In January 1980, the Forest Service published the second comprehensive assessment of the forest and angeland situation in the United States (USDA Forest ervice 1980). The document, in this paper called the Assessment, contained sections on timber, water, range, wildife and fish, recreation, and multiple resource interactions. As part of the sections entitled Range and Multiple Resource Interactions (MRI), a multiresource data set was developed using an intuitive (ID-team) approach.

The procedures involved in producing this multiresource data set have been explained in detail elsewhere (USDA Forest Service 1977, Mitchell and Pickens 1985). Basically, the data set contains estimates for 13 different ecosystem "outputs." Of these, seven pertain to quantifiable resource products: herbage and browse production, net wood growth, wood harvested, domestic livestock grazing, wild ruminant grazing, dispersed recreation use, and water yield. A previous paper evaluated the estimates of herbage and browse production (Mitchell and Pickens 1985).

The purpose of this study was to evaluate the wood harvest and, to a lesser extent, wood growth data contained in the multiresource data set used in the 1980 Assessment. The data structure, discussed below, limits this analysis to various checks of internal consistency and of procedures followed by the ID teams in developing production coefficients.

Description of ID-Team Procedures

The ID-team estimates of these resource outputs were based on a hierarchical partitioning of the forest and range land base of the U.S. according to vegetation classification, land ownership, productivity class (PC), and condition class (CC) (Mitchell and Pickens 1985).

The vegetation classification for timbered and woodland ecosystems was taken from Küchler's (1964) Potential Natural Vegetation system. Several of Küchler's vegetation types were not included (e.g., ponderosa shrub forest, Great Basin pine forest, and juniper steppe woodland) in the Assessment data base, and one nonforested type was added (mountain meadow). Therefore, the amended classification system was renamed Potential Natural Communities (PNC) to mark this distinction.

Ownership criteria were not important for many of the resource outputs. Forage production, for example, on a given site under specified management intensity, should be similar regardless of whether the landowner is the Federal Government or a private citizen. However, such is not the case for timber growth and yield. The Forest Service is restricted by statute in how quickly it can allow trees to be harvested on its lands, while private industry is not. As will be shown later, these differences in rotation length due to land ownership can markedly affect the ID-team estimates for timber growth and harvest. The four owner categories were Forest Service, Bureau of Land Management, other federal, and nonfederal.

Both PC and CC were based on FSH 4809.11 (Forest Survey Handbook). Productivity class referred to the potential productivity of the site for wood growth. Condition class referred to the size category of the dominant trees (table 1).

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[2] *Public Law 93-378. United States Statutes at Large. Volume 88, p. 476 (Pub. L. No. 93-378, 88 Stat. 476).*

[3] *Pub. L. No. 94-588, 90 Stat. 2949.*

Therefore, the Nation's land base was divided, prior to the time that the resource production estimates were developed, by PNC, ownership, PC, and CC categories. Each unique PNC-owner-PC-CC combination was termed a resource unit (RU). The RU constituted the basic land management unit the ID teams used in making multiresource production estimates. Because there were four possible outcomes each for ownership, PC, and CC (table 1), each PNC could have a maximum of 64 RUs associated with it.

The 1980 Assessment defined 107 PNCs. Of these, 63 could be classified as being dominated by either timber or woodland species. In this report, 47 of the 63 forested/woodland PNCs were evaluated (table 2). Those eliminated from consideration were not suited to commercial timber management, e.g., pinyon-juniper, mesquite, and mangrove. Production estimates for the western PNCs were developed at two ID-team workshops held at Fort Collins, Colo., while those for eastern PNCs came from comparable workshops at Athens, Ga.

Management options were defined for the Assessment data as a combination of practices describing a specific target management intensity or level (ML) for each of three resource output groups—timber, range, and wildlife (USDA Forest Service 1977). Timber and range both had six possible MLs and wildlife had three (table 3). In general, the MLs selected for each RU had the same options or a subset of the options chosen for that PNC (Mitchell and Pickens 1985). Approximately 10 management triplets were specified for most PNCs. After ML goals were designated, specific timber, range, and wildlife management practices were selected for each RU in order to attain the desired level (table 4). Management practices were chosen to be consistent with technology existing in the mid-1970s.

The ID-team estimates of timber growth and harvest, in relation to the RU-ML framework described above, were based on an intuitive approach. Intuitive models rely on experts to make estimates based on their training and experience, rather than on mechanistic mathematical descriptors or statistical models produced from actual data (Joyce et al. 1983). Such models are increasingly being used where environmental variables are difficult to quantify and where existing research does not provide a full coverage of the options to be considered.

Net wood growth was defined as the annual change in volume of sound wood in trees greater than 5-inches d.b.h., plus the total volume of trees reaching 5-inches d.b.h., less losses due to natural mortality. Wood harvest was defined as the annual removal of wood taken from trees at least 5-inches d.b.h. for use as wood products, excluding that utilized for fuelwood. Wood harvest was assumed to occur from a regulated forest. Both growth and harvest were expressed in units of cubic feet per acre per year (USDA Forest Serivce 1977).

In order to make the timber growth and yield estimates consistent with other parts of the Assessment data set, they were formatted in a manner counterintuitive to most people familiar with timber growth and yield models. The resource output values recorded in the data set were the average production for a RU in a ML. This implies that, after obtaining a value from the relevant growth or yield table for the time period pertaining to the stand specified CC, a transformation must be applied to conve from total output to annual output within the CC. F timber growth, such a representation is logical; howeve it is unusual for harvest because the product general accrues at one or two points in time. The format wa justified because technically no information was lost i the transformation, and it allowed the timber data t accrue in the same way as the other resources, i. annually.

The simplified example in table 5 illustrates the ide Assume the CC transfer, timber growth, and yiel information shown. Note that the definition of woo growth precluded growth from occurring until CC3. commercial thinning is scheduled for pole-sized tre (CC3) under a given timber ML, the value shown in th data base would reflect an intuitive estimate of tot removal from the thinning operation divided by th forecast number of years in CC3.

Obviously, entries to a data set using the approac described here would be extremely sensitive to rotatio age and the time spent in each CC where harve occurred. Consequently, the data structure makes essentially meaningless to attempt a comparison Assessment estimates obtained by applying composit land base and timber harvest values with field survey dat because, in reality, the U.S. land base is not managed wit the same MLs and rotations that the Assessment dat specify.

The relationship between wood harvest and woo growth may also initially appear unreasonable. Logicall to obtain estimates of yield, the growth function coul be integrated up to the harvest age (Clutter 1963 However, this approach implicitly assumes that what i defined as growth is eventually harvested. In th Assessment data base, the definition of growth does no require harvest to occur, so such an assumption may no be true. Growth can only serve as an upper limit t harvest which may or may not be attained.

Methods

The approach used to evaluate the wood growth an harvest component of the Assessment multiresource dat set was limited by difficulties associated with it verification or validation—see Nolan (1972) for a explanation of model verification/validation. As outline above, the growth and yield estimates could not b directly compared with independent survey data.

Another means of verifying the Assessment estimate i.e., comparison with existing growth and yield table was also deemed to be inappropriate. Because th ID-team estimates, themselves, originated fro references to growth and/or yield equations, such a tas would have amounted to only judging the relativ usefulness of various models. It must be assumed tha the ID teams, with their familiarity with specific PNC selected the most appropriate information sources fo timber growth and yield. Moreover, if an ID tea generated their estimates without referencing suc information sources, the omission should be revealed b some of the logical tests presented below.

Table 1.—Classification categories for timbered and woodland ecosystems used in the 1980 Assessment.

A. Productivity Classes (PC)	B. Condition Classes (CC)
1. 120 + ft^3/acre/yr	1. Nonstocked
2. 85-119	2. Seedlings and saplings
3. 50-84	3. Poles
4. 0-49	4. Sawtimber

Table 2.—List of PNCs from the 1980 RPA Range/Multiple Resource Interaction Assessment evaluated in this report.

Western forests		Eastern forests	
PNC	Name	PNC	Name
1	Spruce/cedar/hemlock	72	Oak savanna
2	Cedar/hemlock/Douglas-fir	73	Oak/hickory/bluestem
3	Silver fir/Douglas-fir	80	Blackbelt
4	Fir/hemlock	82	Cypress savanna
5	Mixed conifer	84	Great Lakes spruce/fir
6	Redwood	85	Conifer Bog
7	Red fir	86	Great Lakes pine
8	Lodgepole pine/subalpine	87	Northeastern spruce/fir
9	Pine/cypress	88	Southeastern spruce/fir
10	Western ponderosa	89	Northern floodplain forest
11	Douglas-fir	90	Maple/basswood
12	Cedar/hemlock/pine	91	Oak/hickory
13	Grand fir/Douglas-fir	92	Elm/ash
14	Western spruce/fir	93	Beech/maple
15	Eastern ponderosa	94	Mixed mesophytic forest
16	Black Hills pine	95	Appalachian oak
17	Pine/Douglas-fir	97	Northern hardwoods
18	Arizona pine	98	Northern hardwoods/fir
19	Spruce/fir/Douglas-fir	99	Northern hardwoods/spruce
20	Southwestern spruce/fir	100	Northeastern oak/pine
24	Mosaic of PNC 2 and Oregon oakwoods	101	Oak/hickory/pine
25	California mixed evergreen	102	Southern mixed forest
		103	Southern floodplain forest
		104	Pocosin
		105	Sand pine scrub

Table 3.—Management levels used in developing the multiresource data base.

Range

A. Environmental management without livestock
B. Environmental management with livestock
C. Extensive management of environment and livestock
D. Intensive management of environment and livestock
E. Environmental management with livestock production maximized
X. Exploitive management

Timber

1. No commercial use
2. Minimal management without assured regeneration
3. Minimal management with assured regeneration
4. Level 3 with commercial thinning
5. Level 4 with precommercial thinning
6. Level 5 plus intensive silviculture such as fertilization

Wildlife

1. No management
2. Manipulation of vegetation
3. Level 2 with physical structure development

Table 4.—Management practices by resource output group used in developing multiresource data set.

Management practice	Units/100 M acres
Range	
Fertilization	M Acres
Irrigation	M Acres
Water control	M Acres
Mechanical vegetation control	
Low cost	M Acres
High cost	M Acres
Vegetation manipulation	
Chemical	M Acres
Biological	M Acres
Fire	M Acres
Debris disposal	M Acres
Mechanical soil treatment	M Acres
Seeding	M Acres
Rodent control	M Acres
Insect and disease control	M Acres
Small water development	Sites
Large water development	Sites
Fence	Miles
Timber thinning	M Acres
Timber	
Planting	M Acres
Direct seeding	M Acres
Site preparation for—	
Natural regeneration	M Acres
Planting and seeding	M Acres
Animal control for—	
Reforestation	M Acres
Timber stand improvement	M Acres
Precommercial thinning	M Acres
Release and weeding	M Acres
Fertilization of established stands	M Acres
Seed production areas	M Acres
Selection and care of superior trees	M Acres
Prescribed burning to control understory	M Acres
Access roads for timber production	Miles
Cutting method	
Shelterwood and seed tree	M Acres
Clearcutting	M Acres
Salvage	M Acres
Selection (high-grading)	M Acres
Selective	M Acres
Wildlife	
Water developments—upland	Sites
Seeding and planting	M Acres
Liming and fertilizing	M Acres
Fencing	Miles
Prescribed burning—uplands	M Acres
Clearing	M Acres
Brush and shrub management	
Mechanical	M Acres
Chemical	M Acres
Biological	M Acres
Pruning	M Acres
Thinning—release	M Acres
Mechanical soil treatment	M Acres
Dens and nest structures	Structures
Perch and nest structures	Structures
Brushpiles and covers	Brushpiles
Streambank stabilizers	Sites

The method selected for evaluating the Assessmen wood growth and yield estimates, given the constraints limiting any direct comparisons, centered around a se of seven questions used to describe differences between the estimation procedures for different PNCs and to check for logical discrepancies with the land productivity definitions. In addition, this approach allowed the determination of how complete the data generating process was in relation to the instructions described in the Book of Procedures (USDA Forest Service 1977), and how well the ID teams documented their assumptions in the PNC management scenarios.

The questions used to evaluate the Assessment wood growth and yield estimates are given below, along with the procedures used to address them.

Question 1. What variation existed in timber yield o practices for the same timber ML when different range or wildlife MLs were specified?

One of the past and, possibly, future uses of the Assessment data set is to analyze resource interactions Question 1 facilitates evaluation of the data set for this purpose by determining whether the ID teams considered the system to be a joint production system in the sense that management actions aimed at production of other outputs affected timber yield or the practices required to get a specific yield.

To evaluate this aspect of the data set, the available MLs for the RUs within a PNC were inspected for the occurrence of one timber ML that occurred with more than one combined range and wildlife ML. For example timber ML 3 might occur with a range ML of B and a wildlife ML of 1 for one management triplet, and with a range ML of D and a wildlife ML of 1 for some other management triplet.

After comparable management triplets were found they were evaluated for implicit interactive intent by two tests. First, the timber practices were compared to see if some adjustment was specified, presumably to offset the impact of the management for other resource outputs Next, the mean annual increment for comparable MLs were calculated and compared.

The following codes were used in recording the results

N= No comparable data.
1= The ID team appeared to modify timber practices and/or yields in response to changing range and wildlife MLs.
2= The ID team did not modify timber practices and/or yields in response to changing range or wildlife MLs.

Question 2. Did the ID teams reference growth and/o yield tables(s) as a basis for their estimates of net wood growth or harvest?

When evaluating intuitive models of wood growth and or yield, it is valuable to know what tables were used by the ID teams. First, the yield table can be used to check both the logic and calculations supporting their estimates. Second, a determination can be made as to whether these values correspond with the predominant timber species being managed in the PNC, as well as

Table 5.—Example of steps to convert growth and yield table entries to required format.

	CC1	CC2	CC3	CC4
Time in CC (years)	5	15	20	25
Cumulative growth through last year in CC (ft^3)	0	0	4000	7000
Growth within CC (ft^3)	0	0	4000	3000
Annual growth in CC (ft^3)	0	0	200	120
Harvest through last year in CC (ft^3)	0	0	0	7000
Harvest within CC (ft^3)	0	0	0	7000
Annual harvest within CC (ft^3)	0	0	0	280

provide a listing of applied yield tables. Finally, the growth and/or yield tables will include relevant definitions of the output predicted.

Each PNC had a management scenario written for it, as specified in the Book of Procedures (USDA Forest Service 1977). The seven topics comprising the management scenario were physiographic description, endangered species, present land use, land use suitability, productivity, rationale for MLs selected, and management practices. When ID teams referenced timber growth or yield tables, documentation to that effect was contained in the productivity section of the management cenario.

Question 3. Did the management scenario deal with ite suitability for timber production?

Once the ID teams obtained (or developed) a potential ange of timber growth and yield output values, they then upposedly adjusted these values to correct for specific characteristics of the PNC or to compensate for management practices. From preliminary analyses of the Assessment data base, it became clear that suitability constituted the primary category of correction made. A knowledge of the site suitability criteria applied to each PNC for timber production facilitates evaluation of the calculated wood harvest mean annual increment.

If suitability criteria were considered by the ID teams, hey were contained in the management scenario of each PNC. Following are examples of some of the factors that were considered to affect suitability: topography, soils, access, bodies of water, and legal restrictions. To measure how comprehensively the ID teams considered suitability when estimating wood growth and harvest, suitability correction factors for each PNC were categorized into four groups: (1) suitability not mentioned, (2) suitability corrections were for the entire PNC only, (3) suitability corrections varied with PC, and (4) suitability corrections varied with ML within PC.

Question 4. How complete was the timber section of he management scenario relative to the instructions set n the Book of Procedures?

An overall review of completeness would provide an ndication of the reproducibility of the ID-team estimates. The estimates referred to here include both management practices as well as net wood growth and harvest. It should be noted that each ID team had members from several disciplines, and each member generally was responsible for one or two scenarios. The individual writing the scenario would naturally be expected to emphasize his or her own resource discipline in this endeavor.

The evaluation of management scenarios was completed in a subjective, but consistent, manner. First, a preliminary review was conducted in order to obtain the range of comprehensiveness represented. After this step, a scale of from 1 to 3 (good, acceptable, minimal) was defined upon which to rate the management scenarios. The scale was based on the quality of information, its presentation, and supporting rationale.

Question 5. Did management scenario indicate any specific timber species managed within the PNC?

This information was essential to evaluate the appropriateness of the growth and yield tables; i.e., if ID team members had, by default, used the indicator species identifying the PNC, definite problems could be expected for those PNCs managed mostly for species not comprising the climax forest communities. Examples of such PNCs include PNC-84 [Great Lakes spruce-fir, which is managed for aspen and birch] and PNC-102 [Southern mixed forest, which is managed for longleaf and slash pine] (Eyre 1980). Although western forests commonly contain large areas of old-growth timber characterizing the PNCs for which they are named, such is more often not the situation. Artifically regenerated Douglas-fir stands have great potential to become increasingly prevalent throughout the Cascade and northern Rocky Mountain ranges, for example (Rehfeldt 1978). In addition, half of the western and more than half of the eastern PNCs are dominated by two or more timber species having different growth characteristics (table 2).

Question 6. Were errors present in the ID-team estimates?

Arithmetic errors in intuitive models are somewhat analogous to coding errors in mathematical models; i.e., searching for errors in coding (logic) tests the interfaces among various model components. Nolan (1972) noted that such a test should be the first step in a model verification/validation process.

The ID-team estimates of wood growth and harvest (mean annual increment) should reflect all corrections, including suitability criteria, time spent in each condition class, and rotation period. Each PNC was spot-checked to ascertain whether calculations built into the ID teams' assumptions actually provided the estimate in the data base.

Question 7. Did the wood growth coefficients appear to be consistent with wood harvest?

Comparison of the net mean annual wood growth with its respective mean annual harvest provided insight into whether the net wood growth coefficients were calculated logically. If the net mean annual wood growth was greater or equal to the wood harvest mean annual increment, then it can be inferred that the ID-team calculations were plausible. However, if the net mean annual wood growth was smaller over the entire rotation period, it can be inferred that the ID teams either made calculation errors or used inconsistent growth and yield tables.

To evaluate wood growth coefficients, net mean annual wood growth for each CC within a PC was computed. These values were then compared to their respective mean annual increments for wood harvest estimates. If the former was greater or equal to the latter, no further evaluation took place. However, if the values for harvest exceeded that for growth, a possible error was inferred, and the CC time periods and net wood growth coefficients were reviewed for noticeable discrepancies.

Results and Discussion

The ID teams varied considerably in how completely they followed procedures and how well documented these procedures were in the various PNC management scenarios. The seven questions are grouped into three categories for discussional purposes; i.e., the multiresource interaction topic (Question 1), data set and procedural documentation (Questions 2, 3, 4, and 5), and presence of logical and/or procedural errors (Questions 6 and 7).

Evaluation of Multiresource Interactions

More than one-half of the 47 PNCs evaluated did not depict an interaction effect (i.e., joint resource production) in response to varying nontimber MLs (table 6).

PNCs from the western (Fort Collins workshops) and eastern (Athens workshops) forests had nearly identical proportions, showing no interaction effect (table 6).

	No. of western PNCs	No. of eastern PNCs
Insufficient MLs	3	4
No interaction	13	14
Interaction	6	7
Total commercial forest PNCs evaluated	22	25

The 13 PNCs showing a resource production interaction effect characterize one attribute of ID-team workshops needing additional emphasis. Of the 12 ID teams meeting at Fort Collins (six teams during each of two sessions), only three accounted for all six western PNCs having an interaction effect. Moreover, just three of the eight Athens ID teams accounted for all seven of the eastern PNCs showing an interaction effect (table 6).

Table 6.—Response of wood harvest and timber management practices to varying range/wildlife MLs in forested PNCs.

PNCs[1] with insufficient MLs to make comparisons

West: 1, 9, 11
East: 82, 88, 104, 105

PNCs showing no interaction effect

West: 2, 4, 5, 6, 10, 12, 13, 15, 17, 18, 19, 20, 25
East: 73, 84, 85, 86, 87, 89, 90, 92, 93, 97, 98, 99, 100, 103

PNCs with an interaction (joint resource production) effect and associated ID teams

	PNC	ID-team Session	
West:	3	3–1	(Fort Collins)
	7	4–1	
	8	4–1	
	14	2–2	
	16	2–2	
	24	3–1	
East:	72	3–1	(Athens)
	80	1–1	
	91	3–1	
	94	1–2	
	95	1–2	
	101	3–1	
	102	1–1	

---

[1] *See table 2 for PNC identification.*

logical deduction from these observations is that a few ndividual ID team members recognized the importance f joint production estimates, and built them into their eams' data sets.

Those groups that did not incorporate joint effects may ave believed that nontimber management has no effect n timber production. It appears likely, however, that they ither did not consider the possible impact of range and vildlife management practices on timber, or did not feel onfident in their ability to make appropriate nodifications. Nonetheless, no evidence exists that ID eams were specifically instructed to consider joint esource production as part of the intuitive estimation rocess.

Only seven PNCs contained insufficient MLs to obtain omparable data. With the exception of Douglas-fir (PNC 1), these were small and contained few timber nanagement levels. The presence of PNC 11 in this group ppeared anomalous.

ata Set and Procedural Documentation

Unlike the previous section, which showed no lifference between eastern and western PNCs in relation o the question being asked, information concerning data et and procedural documentation was conspicuously lependent upon whether the PNC represented an eastern r western forest.

In general, ID teams dealing with eastern PNCs Athens workshops) more completely documented their vood production estimates by referencing growth/yield ables (Question 2) and site suitability factors (Question). These ID teams additionally provided more complete imber sections of their management scenarios (Question), and included references to particular tree species eing managed (Question 7). One possible contributing actor may be that, because the eastern workshops were onducted after the western workshops, improved nstructions may have been given based on experience ained.

Reference to growth/yield tables.—Twelve of the 22 vestern PNCs (55%) contained no reference to a growth r yield table in their management scenarios; however, nly 5 of the 25 eastern PNCs (20%) fell in this category table 7). In addition, all of the mangement scenarios aving references to more than one growth/yield table vere for eastern PNCs. Such a situation probably reflects he greater availability of a variety of growth/yield tables or eastern forests, especially in the Southeast, rather han indicating that ID teams meeting in Athens did a nore thorough job.

The problem of lack of references of wood growth/yield ables is somewhat intensified by the incompleteness of everal references that were cited. References listed for hree of the western PNCs (PNCs 17, 18, and 20) and even of the eastern PNCs (PNCs 80, 86, 87, 88, 99, 102, nd 105) were found to be inadequate to allow them to e acquired in a library search. Of these, only two of the astern PNC management scenarios contained additional eferences; for the remainder, the incomplete reference was the only one cited. If the PNCs with all unverifiable references to wood growth/yield tables are included with those containing no reference, then two-thirds and two-fifths of the western and eastern PNCs, respectively, would have been classified as having no references.

Reference to site suitability.—Most of the western PNCs contained some reference to suitability for timber production in their management scenarios, but less than one-half of the eastern PNCs were so categorized (table 8). This was to be expected. Western forests tend to have rugged topography, limited access, fragile soils. and more legal restrictions such as silvicultural restraints in forest practices acts—all factors requiring suitability corrections in the ID-team estimates. However, these factors, and others more prevalent in the East, such as lakes and reservoirs, also affect wood production in eastern forests and probably should have been considered more comprehensively by those ID teams. Again, the results emphasize the requirement for consistent and thorough training of ID teams before the estimation process begins.

Completeness of timber management scenarios.—For the most part, the evaluations of management scenario completeness reflected favorably on the ID teams. Only 3 of the 47 management scenarios examined failed to rate above the minimum acceptable level based on quality of information, its manner of presentation, and supporting documentation (table 9).

Somewhat unexpectedly, the comprehensiveness of management scenarios was not related to ID teams. Each of the six western PNCs rated as good, for example, was written by a different ID team. Six of the eight eastern ID teams were responsible for the eastern PNCs rated as good.

Reference to tree species being managed.—Five of the western and 13 of the eastern PNCs had references to specific tree categories or species when discussing wood growth and yield information (table 10). Examined another way, 13 of the western PNCs, but only 4 of the eastern PNCs, included no reference to either growth/yield tables or key timber species in their management scenarios. Whether a training difference between the Fort Collins and Athens workshops was partly responsible for this disparity cannot be ascertained. ID teams responsible for western PNCs may have incorrectly assumed that the principal timber species characterizing their forests was intuitively obvious.

Logical and Procedural Errors

The wood growth and harvest estimates were, on the whole, free of noticeable errors. In fact, an appraisal of these estimates in terms of Question 4 (Were errors present in the ID team estimates?) turned up no obvious mistakes; i.e., the arithmetic applied for each PNC was done correctly as defined in its management scenario for the values checked. It should be noted, however, that only a few data entries were checked for logical and procedural errors in each PNC.

In regard to Question 5 (Did the wood growth coefficients appear to be consistent with wood harvest?), only a few discrepancies were discovered. Most were small

Table 7.—Categorization of PNCs by number of references to growth and/or yield tables.

PNCs[1] with no reference cited

West: 6, 7, 8, 9, 11, 12, 13, 14, 15, 16, 19, 25
East: 72, 82, 89, 101, 104

PNCs with one reference cited

West: 1, 2, 3, 4, 5, 10, 17, 18, 20, 24
East: 73, 80, 84, 91, 98, 99, 102, 103, 105

PNCs with more than one reference cited

East: 85, 86, 87, 88, 90, 92, 93, 94, 95, 97, 100

[1] *See table 2.*

Table 8.—Classification of PNCs[1] in relation to their degree of specificity concerning suitability criteria for timber production.

No suitability criteria mentioned for PNCs

West: 6, 9, 16, 20
East: 82, 84, 86, 90, 91, 92, 93, 94, 95, 97, 98, 99, 104, 105

Suitability criteria applied to PNCs as a whole

West: 7, 8, 10, 11, 12, 14, 15, 17, 18, 24, 25
East: 72, 73, 85, 88, 89, 100, 101, 103

Suitability criteria applied to PC within PNC

West: 1, 2, 3, 4
East: 80, 87, 102

Suitability criteria applied to ML within PC

West: 5, 13, 19

[1] *See table 2.*

Table 9.—Overall rating of PNC timber management scenarios based on quality of information, manner of presentation, and supporting documentation.

PNCs rated as good

West: 5, 10, 13, 14, 19, 20
East: 72, 73, 80, 82, 85, 88, 94, 97, 100, 101, 102, 103

PNCs rated as acceptable

West: 1, 2. 3, 4, 6, 7, 8, 9, 11, 15, 16, 17, 18, 24
East: 84, 86, 89, 90, 91, 92, 93

PNCs rated as minimal

West: 12, 25
East: 87

differences that could, presumably, be attributed to rounding errors when summing across CC. It should be noted that little effort was made by the RPA Range and MRI staffs to validate the wood growth estimates. Different ID teams were suspected to have defined growth differently (e.g., net versus gross wood growth); therefore, corrections applied collectively to all PNCs would have been inappropriate in any case.

Table 10.—Reference to timber species or category managed for wood production by PNC.

	Timber Species/Category
Western PNCs	
2	Douglas-fir
4	Softwoods[1]
5	Softwoods
9	Monterey pine
18	Ponderosa pine
Eastern PNCs	
72	Hardwoods[1]
73	Hardwoods
80	Hardwoods, Softwoods
84	Aspen
85	Softwoods
86	Softwoods
88	Softwoods
89	Cottonwood
90	Sugar maple
98	Hardwoods
102	Softwoods
104	Loblolly pine
105	Sand pine

[1] *Management scenario referred to several species of softwoods/hardwoods or to softwoods/hardwoods, in general.*

Conclusions

Given the newness of ID-team approaches to natural esource problem-solving in 1977, the wood growth and arvest estimates used in the 1980 Range and MRI ssessments were reasonable. Perhaps the most impor-ant conclusion to ensue from this study has nothing to o with the wood production estimates per se. Rather, he results have more profound implications on the train-ng of ID teams.

First, all important concepts and terms must be horoughly defined and emphasized so each team and/or nember understands them in the same way. For xample, if the significance of joint resource production s construed to be an essential part of the wood growth/arvest data set, it should be properly described and tressed during the training period.

Second, ID teams should comprehensively describe, n writing, all assumptions made and technical methods sed in the estimation process. Such documentation ecomes imperative if ID-team outputs are to be subject o later verification or evaluation. In addition. citations f all references used must be complete. Holling (1978) as argued that effective communication, which includes escriptions of assumptions and methods, is essential if nalyses such as are described in this report are to have n impact on decisionmaking.

Although the data, for the most part, appeared lausible and were moderately well documented, a efinite need exists for their complete verification and pdating if they are to be used again in national ssessments or similar applications. An adequate erification/updating might contain several steps.

1. Development of algorithms (software) to automate he data evaluation. This process would integrate the time period within each CC for a given type of land (PNC-owner-PC combination) with associated management practices and output estimates. This would provide a summary of the management level in a format more familiar to a timber management specialist, the practices applied over a set rotation and the resulting timber growth and yield estimates.

2. A review by qualified timber management specialists of the results of Step 1. Such a review would be conducted on all PNCs to select those needing correction or clarification. Step 2 might reveal changes in Step 1 that would more appropriately present the timber implications for appraisal, thereby making Steps 1 and 2 recursive in nature.

3. Estimation of wood growth and yield for each PNC in need of revision. This step would be performed by appropriate timber management specialists under the supervision of the individual carrying out Step 2. Because only the timber resource would be at issue, the entire ID-team process would not need to be repeated.

Within the updating framework, the timber practices could be modified, but only to the extent of clarifying the intent of the original ID teams. If timber management practices are modified beyond the original ID teams' intents, then the ID-team process should be repeated.

If it is decided that the Assessment data base should be used for applications different from the linear programming framework for which it was developed, some precautions should be considered. First, the potential users must decide whether the data are sufficiently accurate to support their application. Also, users must determine if the data are presented in an appropriate manner, and, if not, whether they can be transformed to a useful form. If, for example, a user is concerned with the timing of harvests, a problem might arise when the schedule for harvest practices indicates both a thinning and final harvest in CC4. Determining the proportion of volume removed by thinning or the date of thinning is not possible from the practices alone. Such needed information will not always be available in the management scenario.

Literature Cited

Clutter, J. L. 1963. Compatible growth and yield models for loblolly pine. Forest Science 9:354-371.

Erye, F. H., editor. 1980. Forest cover types of the United States and Canada. 148 p. plus map. Society of American Foresters, Washington, D.C.

Holling, C. S., editor. 1978. Adaptive environmental assessment and management. 376 p. John Wiley & Sons, New York, N.Y.

Joyce, L. A., B. McKinnon, J. G. Hof, and T. W. Hoekstra. 1983. Analysis of multiresource production for national assessments and appraisals. USDA Forest Service General Technical Report RM-101, 20 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Küchler, A. W. 1964. Potential natural vegetation of th conterminous United States. Special Publication No 36, 116 p. plus map. American Geographical Society New York, N.Y.

Mitchell, J. E., and J. B. Pickens. 1985. An evaluatio of herbage and browse production estimators used i the 1980 RPA assessment. USDA Forest Servic Research Paper RM-259, 32 p. Rocky Mountain Fores and Range Experiment Station, Fort Collins, Colo.

Nolan, R. L. 1972. Verification/validation of computer simulation models. p. 1254-1265. *In* Summe computer simulation conference. [San Diego, Calif. June 14-16, 1972]. Simulation Council, La Jolla, Calif

Rehfeldt. G. E. 1978. Genetic differentiation of Douglas fir populations from the northern Rocky Mountains Ecology 59:1264-1270.

USDA Forest Service. 1977. RPA-79 assessment—Boo of procedures, framework for supply analysis. Rang and multiresource use interaction elements. 109 p Washington, D.C.

USDA Forest Service. 1980. An assessment of th forest and range land situation in the United States. FS-345. 631 p. Washington, D.C.

Mitchell, John E., and James B. Pickens. 1986. An evaluation of procedures used to predict timber growth and harvest in the range and multiple resource interactions sections of the 1980 RPA Assessment. USDA Forest Service General Technical Report RM-124, 10 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Interdisciplinary (ID) team estimates of wood growth and harvest used in the Range and Multiple Resource Interactions sections of the 1980 RPA Assessment were evaluated by checking for the presence of joint resource production estimates, examining data set documentation, and searching for logical and procedural errors. Apparent deficiencies in ID-team training and procedural documentation were found to limit the usefulness of the wood growth and harvest estimates.

Keywords: Timber growth, timber harvest, Resources Planning Act, national assessment, interdisciplinary teams, intuitive models.

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

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United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

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Proceedings: Intermountain Nurseryman's Association Meeting

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**August 13-15, 1985
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Abstract

Twelve invited papers were presented on a variety of topics of interest to nursery managers growing bareroot and/or containerized seedlings. Nine additional papers were presented in the form of small group workshops on weed control, seedling quality, and bareroot seedling fertilization.

Keywords: Tree nurseries, greenhouses, tree seedlings, containerized seedlings.

USDA Forest Service
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Fort Collins, Colorado

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Contents

Page

Value of Windbreaks 1
Sheridan I. Dronen

In-Bed Herbaceous Windbarrier Produced More Ponderosa Pine Seedlings 3
Richard W. Tinus

Administrative, Economic, and Technical Observations in Developing and Maintaining an Effective Weed Control Program 7
Al Myatt and Michael Vorwerk

Nursery Research: A Practical Approach 10
G. Bruce Neill

Soil Compaction: Effects on Seedling Growth 12
Steven K. Omi

Computer Use in Nursery Management 24
Jerry Grebasch

Recent Developments in the Management of Nursery Pests 28
Whitney S. Cranshaw

Greenhouse Production of Quaking Aspen Seedlings 31
Karen E. Burr

Fertilizer Trials on Containerized Red Pine 38
Kent L. Eggleston and Ruth Crownover Sharp

Stratification and Germination of Western White Pine Seeds 43
Rodger Danielson

Development of Underground Cold Storage at Pine Ridge Forest Nursery 45
J. Roger Hamilton

Effects of Ethylene on Development and Field Performance of Loblolly Pine Seedlings 48
James P. Barnett, Jon D. Johnson, and Nancy J. Stumpff

WEED CONTROL PANEL

Herbicides for Weed Control in Tree Nurseries 54
Lyle K. Alspach

Forest Tree Nursery Herbicide Studies in the Northern Great Plains Herbicide Phytotoxicity Tables 58
Lawrence P. Abrahamson

Herbicides for Conifers: What's New 68
Robyn L. Darbyshire

SEEDLING QUALITY PANEL

Principles, Procedures, and Availability of Seedling Quality Tests 71
Kenneth R. Munson

When to Measure Seedling Quality in Bareroot Nurseries 78
David G. Simpson

How to Use Seedling Quality Measurements in Container Nurseries 84
C. J. Sally Johnson

BAREROOT SEEDLING FERTILIZATION PANEL

How to Determine Fertilizer Rates and Application Timing in Bareroot Forest Nurseries 87
T. D. Landis and J. W. Fischer

Soil Mapping and Testing 95
Randy Selig

How to Maximize Efficiency of Fertilizers in a Forest Tree Nursery 99
Ivor K. Edwards

POSTER PAPER

Cold-Hardiness Testing of Conifer Seedlings 104
Karen E. Burr, Stephen J. Wallner, and Richard W. Tinus

BUSINESS MEETING NOTES 109

LIST OF ATTENDEES 110

Pesticide Precautionary Statement

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers—out of reach of children and pets—and away from foodstuff.

Apply pesticides selectively and carefully. Do not apply a pesticide when there is danger of drift to other areas. Avoid prolonged inhalation of a pesticide spray or dust. When applying a pesticide, it is advisable that you be fully clothed.

After handling a pesticide, do not eat, drink, or smoke until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If the pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

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U.S. DEPARTMENT OF AGRICULTURE

Value of Windbreaks[1]

Sheridan I. Dronen[2]

Abstract.--Windbreaks are an important part of in the Great Plains. They are planted for a variety of reasons and provide both economical and esthetic benefits. This is a summary of some of the benefits and the importance of using adapted, high quality nursery stock.

Early settlers in the Great Plains found trees growing only in the drainageways and river bottoms. Due to the relentless wind, they soon recognized the need for windbreaks. They found that it wasn't an easy task to move trees from the river bottoms to the prairie, but with care it was possible. The benefits of windbreaks in the Great Plains have been recognized since these early days.

Starting with the Timber Culture Act of 1873 up to the present, millions of seedlings have been planted in windbreaks on the Great Plains. In South Dakota alone, over 150 million seedlings have been planted from 1935-85. These windbreaks are planted for a variety of reasons but mainly as a barrier to reduce wind velocity. Reducing the wind velocity alters factors of the microclimate, such as humidity and temperature, in the protected zone. Windbreaks conserve moisture because they reduce evaporation and transpiration in summer and trap snow in winter. Windbreaks protect farm and ranch homes, cultivated fields, gardens and orchards, livestock feedlots, and wildlife.

There have been many studies on the economic value of windbreaks. In a recent study in Saskatchewan, White (1984) found that a properly designed shelterbelt can reduce the heating of a typical farm home by $585 per year. This reconfirms an earlier study by Bates (1945) that showed about a 25 percent reduction in heating costs.

A study by Ames (1980) calculates the increased maintenance feed costs for beef cattle per degree of cold. This method shows a windbreak can reduce the maintenance feed costs for beef cattle by 10 percent on a winter day of 15°F and 15 mph winds. Savings are even greater as the temperature drops and the windspeed increases.

Dr. Brandle (1980) has published some interesting work in Nebraska on the benefits of field windbreaks. His studies show field windbreaks can increase winter wheat yields by 8 bu./ac. and soybeans by 4 bu./ac.

These studies and others show monetary benefits from planting windbreaks. How do you put a monetary value on raising a nice flower garden in the protected area of a windbreak on the windswept Plains? These nonmonetary values are also important reasons for windbreaks.

I want to switch gears a little now and talk about why we have good windbreaks and why we've been able to keep a good windbreak program going in the upper Midwest. I feel one of the most important factor is that we have a lot of high quality windbreaks and high quality windbreaks sell themselves. This quality is the result of research and information gathering that was started in the late 1800's and has continued up to the present.

During the 1890's, state agricultural experiment stations throughout the Plains established tree planting tests to determine the best adapted species. USDA field stations at Mandan, North Dakota; Cheyenne, Wyoming; Akron, Colorado; and Woodward, Oklahoma began tree planting experiments during the period 1910-20. This work is still the basis for our present windbreak planting program. The list of species (table 1) used in the 1916 shelterbelt project at Mandan isn't much different than the species that are most commonly planted today (table 2). This comparison is important because it shows us how limited we are in species selection. This is especially true for tall trees adapted to dry sites.

---

[1] Paper presented at the Intermountain Nurseryman's Association Meeting, University Park Holiday Inn Hotel & Convention Center, Fort Collins, Colorado, August 13-15, 1985.

[2] Sheridan I. Dronen, Staff Forester, USDA, Soil Conservation Service, Huron, South Dakota.

Tall deciduous trees	Medium-height deciduous trees	Conifers	Shrubs
Green ash	Chokecherry	Ponderosa pine	Common buckthorn
Boxelder	Russian-olive	Scotch pine	Silver buffaloberry
Cottonwood	Tatarian maple	Eastern redcedar	Tatarian honeysuckle
American elm		Black Hills spruce	Siberian pea-tree
Siberian elm		Blue spruce	American plum
Hackberry			
Honeylocust			
Golden willow			

Table 1.--Cooperative Shelterbelt Project 1916-46
(George 1953)

Tall deciduous trees	Medium-height deciduous trees	Conifers	Shrubs
Green ash	Amur maple	White (Black Hills) spruce	American plum
Hackberry	Chokecherry	Blue (Colorado) spruce	Caragana
Honeylocust	Manchurian crabapple	Eastern redcedar	Lilac
Poplars	Russian-olive	Ponderosa pine	Peking cotoneaster
Siberian elm	Siberian crabapple	Rocky Mountain juniper	Silver buffaloberry
Willows		Scotch pine	Tatarian honeysuckle

Table 2.--Species used in the Northern Great Plains
(Dronen 1984)

How do we improve our windbreaks? The chances of finding many new species aren't very good; the real chance for improvement lies in improving the species we have and using the best known seed sources for seedling production. That's why the nurseryman is so important in the success or failure of our windbreak program.

Another area where the nurseryman is extremely important is in seedling grades. In the Dakotas' we have established minimum and maximum grades for nursery stock for all the species that are used in windbreaks. These grades were established from research and practical experience.

E. J. George (1973) found that there was significant differences in height and diameter growth of green ash with four grades of seedlings. His study was established in 1941. The four grades: 1, 2, 3, and 4 averaged 2.9, 1.8, 1.5, and 0.8 feet in height and .52, .33, .22, and .15 inches in diameter, respectively, at planting time. Grades 1 and 2 showed superior height and diameter growth over grades 3 and 4 after 29 years in the field. Regardless of the cause, genetic or bed density, seedlings having the larger stem diameter at one year continued to have that characteristic when grown for a second season in the nursery.

I like to use the comparison with the runt in a pig litter. It never catches up with the rest of the litter. In the nursery, seedlings that don't make grade should be thrown away. This is especially true for tall trees. Height is one of the most important factors for influencing the values of a windbreak because the area protected by a windbreak is 10 times the height. Therefore, every additional foot of height provides 10 feet extra width of area protected. In the George study (1973) there was about a 9-foot difference between the number one grade and the number four grade seedlings. This increased the width of the area protected by 90 feet!

For many people, planting a windbreak is a once in a lifetime experience. You, the nurseryman, can assure that adapted seed sources and high quality seedlings, properly graded, are used to ensure the best possible start and give the windbreak a good chance of being successful.

LITERATURE CITED

Ames, D., Livestock Nutrition in Cold Weather, Animal Nutrition & Health, pp. 6-7 and 38-39, October 1980.

Bates, C. G., The Value Of Shelterbelts In House-Heating. Journal Of Forestry, Vol. 43, pp. 176-196, 1945.

Brandle, J. R., the Role of Microclimate in Energy Use Efficiency, Paper No. 6150, Journal Series, Nebraska Agricultural Experiment Station, November 1980.

Brandle, J. R., B. B. Johnson, and D. D. Dearmont, Field Windbreak Economics, Paper No. 6966, Journal Series, Nebraska Agricultural Experiment Station, 1982.

Dronen, S. I., Windbreaks In The Great Plains. Northern Journal Of Applied Forestry, Vol. 1 No. 3, pp. 55-59, September 1984.

George, E. J., 31-Year Results In Growing Shelterbelts On The Northern Great Plains, USDA, Circular No. 924, August 1953.

George, E. J. and A. B. Frank, Graded Nursery Stock In Shelterbelt Type Planting Evaluated Over 29-Year Span. Tree Planters' Notes, Volume 24, No. 1, pp. 30-32, 1973.

White, Robert, Shelterbelts Help Cut Heating Costs. Farmers Light & Power, February 1984.

In-Bed Herbaceous Windbarrier Produced More Ponderosa Pine Seedlings[1]

Richard W. Tinus[2]

Abstract.--There are currently no windbreaks at the Albuquerque Tree Nursery, but experience at other nurseries indicates windbreaks can be highly beneficial. To test the concept quickly without erecting or growing anything permanent, one drill row of oats was sown per bed when the rest of the bed was sown to ponderosa pine. The oats, which were maintained at 30 cm height by mowing, reduced wind velocity at ground level by 79%. In spite of a 25% loss of seedbed space (row 8 to planted oats and row 7 to competition from the oats), there were 55% more seedlings per running meter of bed with the windbarrier (6 rows) than without the windbarrier (8 rows). With the windbarrier, increases in seedling fresh weight and epicotyl height, and greener color were observed, but variability was too great for the differences to be significant. Windbarriers in adjacent beds across a section had no significant cumulative effect.

INTRODUCTION

Strong winds can be highly damaging to young seedlings. Since most nurseries experience strong winds at least occasionally, some form of wind protection is usually needed (Tinus 1978). Agronomic studies have also shown improved crop growth behind windbreaks even in situations where the wind is not strong enough to cause direct damage (Tinus 1976). However, the effects of windbreaks are not all beneficial, and careful planning is needed to maximize benefits while minimizing unwanted side effects (Read 1964, Stoeckler 1962).

Any windbreak has three primary characteristics: height, density, and orientation. The primary effect is reduction of wind velocity on the lee side. The pattern of wind velocity reduction is independent of barrier height, but the protected area is proportional to the height; therefore, the effect of a windbreak at any distance from it can be measured in terms of multiples of barrier height (H) (Read 1964). For complete protection, the array of barriers should be spaced about 10 H apart. That means a row of trees 15 m tall will protect an area out to 150 m from the trees, whereas a 1.3-m snow fence will protect only 13 m.

Trees and snow fences have been the main windbreaks used in nurseries. Trees have the disadvantage that they take years to grow to a useful size, and they may harbor pests that attack the crop trees. To be effective, snow fences must be erected in the middle of each section, where they tend to get in the way of farming operations and are a nuisance to put up and take down.

The Albuquerque Tree Nursery is currently devoid of windbreaks, but some small-scale experiments and observations indicate that windbreaks might be useful. In a recent nursery study, Douglas-fir, white fir, and Engelmann spruce seedbeds that were covered with snow fence on sideboards produced more and larger seedlings, but there was no apparent response by ponderosa pine. However, for protection from rabbits, the whole experiment was surrounded by 1-m-high, 6-mm hardware cloth, which is also an effective windbreak; and the growth of ponderosa pine within and close to the enclosure was clearly better than at distance beyond the windbreak influences.

From the apparent benefit of wind protection without significant shade, without interfering with cultural operations and at low cost, came the idea for an herbaceous windbarrier to be planted in one drill row of each bed of ponderosa pine. Oats were selected, because it is a cool-season grass that would reach an effective height quickly in the 1-0 season and die overwinter. If mowed to prevent heading out, it would not become a weed problem.

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[1] Paper presented at the Intermountain Nurseryman's Association Meeting, August 13-15, 1985, Fort Collins, CO.

[2] The author is principal plant physiologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, AZ.

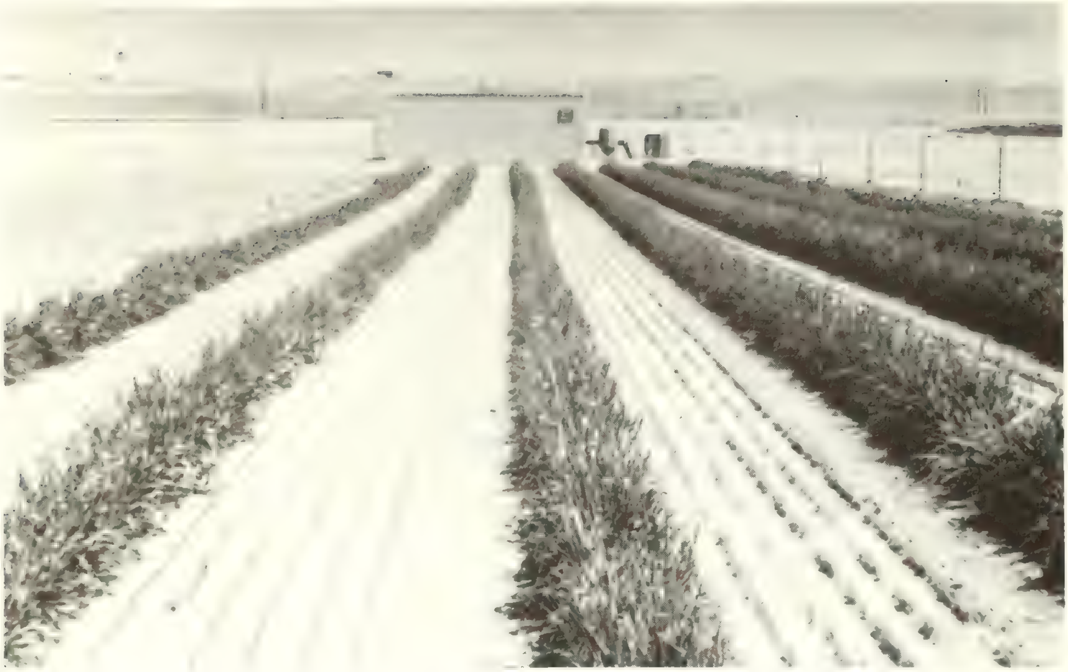

Figure 1.--Ponderosa pine at Alburquerque Tree Nursery in July of the first season with an oat windbarrier, just before mowing to 30 cm

MATERIALS AND METHODS

At Albuquerque Tree Nursery, the beds are oriented north to south, almost perpendicular to the strongest winds during the growing season. In May 1983, the seven beds of one nursery section were sown to ponderosa pine in seven drill rows. The eighth (westernmost) drill row in each bed was sown to Cimmaron oats, a tall-stemmed variety of Texas origin (fig. 1). The oats were sown fairly thick (about 65 seeds per running meter) to insure a windbarrier of adequate density. Another nursery section sown entirely to ponderosa pine with no oats served as the control. Windbreak and control sections were separated from each other and to the sides by fallow sections. Windbreak and control sections were replicated twice, all on about 2 ha of the nursery that were reasonably uniform in soil texture. In the middle of each windbreak and control section, a totalizing cup anemometer was installed, recessed into the ground so that the cups were just above ground level at the expected seedling crown height.

Seedling cultural treatments, such as irrigation, fertilization, and weed and pest control, were the same as elsewhere on the nursery. When the oats began to head out at 50 cm in height at the end of June (fig. 1), they were mowed to 30-cm height.

The four anemometers were read weekly throughout the first and second growing seasons. At the end of each growing season, two randomly located but widely spaced transects were laid out perpendicular to the sections. The two transects across two field replications were treated as four block replicates for statistical purposes. All of the seedlings in a 30-cm strip were lifted by hand and kept separate by drill row.

The seedlings in each sample plot (30-cm strip of drill row) were counted and bed density computed. On a random subsample of 10 seedlings (or fewer, if there were not 10), fresh weight, epicotyl height, and foliage color were measured. Foliage color varied from dark green to yellow and was measured by an index keyed to the followin Munsell standard colors (Anon. 1977):

Index	Color	Munsell code
4	dark green	7.5 G 4/4 to 2/4
3	light green	7.5 GY 5/6 to 5/8
2	yellow green	5.0 GY 6/6
1	yellow	2.5 GY 7/6 to 7/8

The color index was treated as a continuous variable, as were the other measurements, and analyzed as a randomized block design with beds within treatment and rows within beds treated as split plot and split-split plot factors, respectively. Only six rows per bed were analyzed to balance sample size between treated and control blocks.

RESULTS AND DISCUSSION

Reduction of Wind

After the oats had reached about 50 cm in height by the beginning of July (fig. 1), and for the remainder of the first growing season after the oats had been mowed, the oat windbarrier reduced surface wind by 74%, or to only 26% of what it was with no windbreak. This result was as expected for a moderately dense windbreak at a distance of about 2.5 H (Tinus 1976). The oats remained standing overwinter and throughout the second growing season, during which they reduced surface wind to 21% of total wind with no protection. Therefore, for at least 16 months, the oats were a highly effective windbreak within about 10-15 cm of the soil surface.

Main Effects of Windbreak

Seedling numbers were strikingly affected by the oat windbarrier. Competition and shading from the oats (in row 8) was so strong that seedlings grew poorly in row 7. Therefore, for the following comparisons, it was assumed that no usable trees would be produced in rows 7 and 8 with the windbarrier. To simplify analysis, rows 1 through 6 with a windbarrier are compared with rows 1 through 6 without the windbarrier.

At the end of the first season, the differences in seedling number and size, with or without a windbarrier, were not significant. However, by the end of the second season, bed density without a windbarrier was 104 seedlings per square meter, but 215 per square meter with a windbarrier (106% greater); and seedlings per lineal meter of bed (which includes rows 7 and 8 where there was no windbarrier) was 127 and 197, respectively, or 55% greater. Fresh weight and epicotyl height were greater and foliage color greener with a windbarrier than without in some, but not all, of the replications. Variability was too great for these differences to be significant.

Cumulative Effect

If linear multiple windbreaks are spaced closely enough so that the effect of one is not completely dissipated before the next one is encountered, there may be a cumulative effect up to as many as four windbreaks (Read 1964, Tinus 1976). In this experiment, such an effect was sought by comparing beds within treatments; however, no significant differences were found, except that at the end of the first year, foliage color tended to be yellower in the eastern beds than in the western, and the difference in color was greater in beds without a windbarrier than with one. Thus, there is little evidence of any cumulative effect.

Within-Bed Effects

At the end of both the first and second seasons, there were distinct differences in seedling number, size, and color by row within bed (fig. 2). Number of seedlings followed no pattern

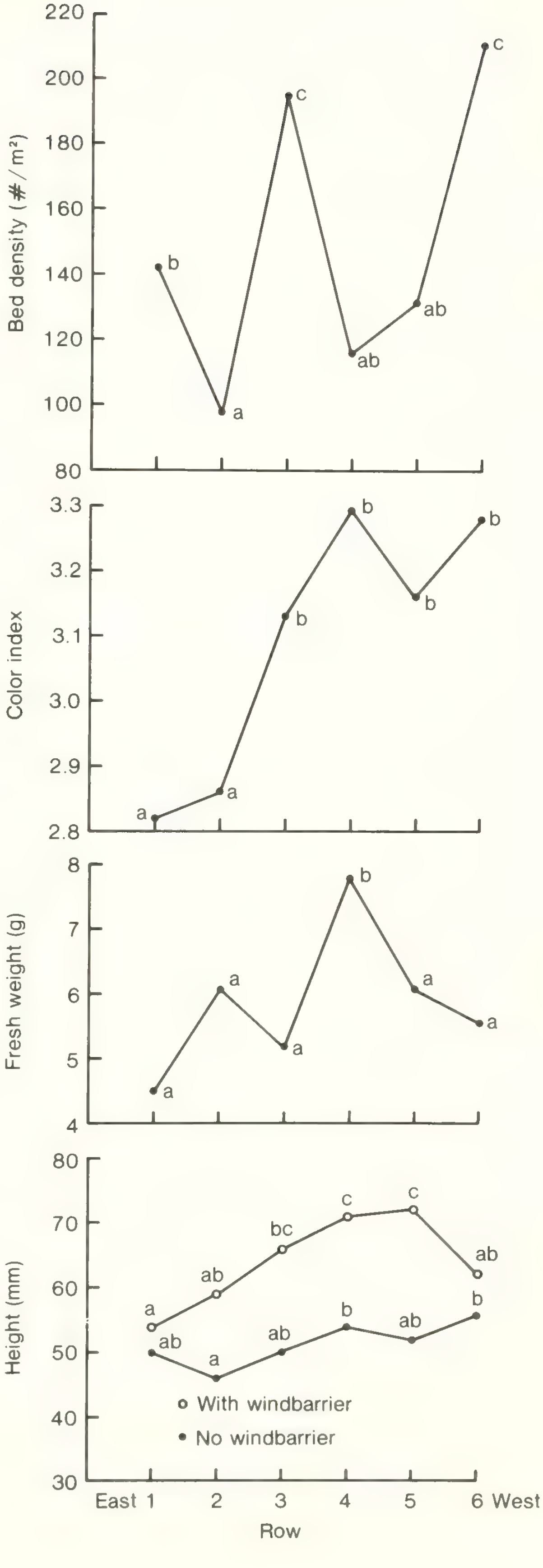

Figure 2.--Number, size, and color of 2-0 ponderosa pine seedlings as a function of row within bed. Bed density, color, and fresh weight showed similar patterns with or without a windbarrier. Points on a given line with the same letter are not significantly different at p=0.05 by an F-protected LSD test.

that could be related to the experiment; but the pattern was the same with or without the windbarrier, in both first and second seasons. It may have been caused by nonuniform sowing or seed covering.

With the windbarrier, epicotyl height and fresh weight were largest in the middle rows and declined on either side creating a distinct "breadloaf" effect. This is evidence of the competition from the oats and was expected. Growth and tree numbers were so strongly depressed in row 7 (adjacent the oats in row 8) that this row was deleted from calculations of size and number of seedlings produced with the windbreak.

Although there were some significant differences in beds without a windbarrier, there was not a clear pattern. Sometimes a breadloaf pattern is observed in beds of not only tree seedlings, but of horticultural and agronomic crops (Tinus 1976). As the seedlings gain height and foliage density, they become a windbarrier in themselves and protect their neighbors to the lee side.

Seedling color tended to be greener in the middle and western rows and more chlorotic in the easternmost rows, with or without a windbarrier. In the first season, the effect was more pronounced without a windbarrier than with one. Sometimes growth in the outermost rows of a bed is poorer because of exposure, wheel compaction of the alley between beds, or sloughing of the edge of the bed. However, there was no evidence for any such conditions in this experiment. A second possible explanation is that the most detrimental winds come from the east. If so, local weather records could indicate the time of year and circumstances under which windbarriers would be most useful.

CONCLUSIONS

More ponderosa pine seedlings were produced in six rows per bed with an oat windbarrier than were produced in eight rows without it. The effectiveness of the windbreak was due in part to seedbed orientation, because the beds are laid out perpendicular to the prevailing strong winds. Thi technique shows promise as a means for a nursery to obtain wind protection for the seedbeds quickly with little capital expenditure. As with all innovations, however, it should be treated on a small scale on an area typical of the nursery as a whole to determine if the benefits warrant the costs, before being applied to the whole nursery.

LITERATURE CITED

Anonymous. 1977. Munsell color charts for plant tissues. Kollmorgen Corp., Baltimore, Md.

Read, R. A. 1964. Tree windbreaks for the centra Great Plains. Agriculture Handbook 250, 68 p. U.S. Department of Agriculture, Washington, D.C.

Stoeckler, J. H. 1962. Shelterbelt influence on Great Plains field environment and crops. Forest Service Product Research Paper 62, 2 p. U.S. Department of Agriculture, Washington, D.C.

Tinus, R. W., editor. 1976. Shelterbelts on the Great Plains: Proceedings of the symposium. [Denver, Colo., April 20-22, 1976] Great Plains Agriculture Council Publication 78, 218 p.

Tinus, R. W. 1978. Shelterbelts for nurseries. p. B-154-164. In Proceedings of the Western Forest Nursery Council and Intermountain Nurserymen's Association Workshop [Eureka, Calif., August 7-11, 1978]. R. W. Gustafson editor. U.S. Department of Agriculture, Forest Service, State and Private Forestry, San Francisco, Calif.

Administrative, Economic, and Technical Observations in Developing and Maintaining an Effective Weed Control Program[1]

Al Myatt Michael Vorwerk [2]

Weed control is an important part of a nursery operation. As managers we should be concerned with not only the technical aspects of an effective weed control program but influence we have on the "human resources" as well.

As managers we spend between 60 to 80 percent of our operations budget on human resources-salaries. And according to the July 11, 1985 issue of the Wall Street Journal, titled, "Loyalty Ebbs at Many Companies as Employees Grow Disallusioned", we may have some room for improvement. The graph shows that since 1970 there has been an increased dissatisfaction in all management levels of the work force. Sick leave is up to over 13%.

What does this have to do with weed control? An effective weed control program is carried out by people who will do, not by people who can do.

All the technical knowledge in the world is of little importance if it is not applied, or applied wrong, or applied at the wrong time under the wrong conditions because of lack of desire to be effective on the part of the employee. This intangible inner drive called motivation is directly related to the degree of employee commitment to the job and the organization.

As a manager what do you do to effectively utilize this resource? Does your interviewing program allow your staff to assist in hiring the person they will be supervising or working with? As a supervisor were you trained in the art of interviewing? Do you have written job descriptions and have an understanding of what type of characteristics you are looking for in an applicant? Do you hire someone to fill a specific beginning level position without considering him for higher level positions.

Do you have an effective training program for teaching the employee the technical skills needed for his job? Does your program include communications and team building skills, policies and functions of the organization and skills needed for supervision and promotion?

Do you have a written annual plan or work that the staff has helped you develop?

Do you have a review system that allows you to work with an employee on what needs to be accomplished? Provide them with different levels of goals so that the work is challenging while evaluating their progress on a regular basis.
Does your program reward them for their success? Remember even if money is limited, praise is free.

The skills and knowledge acquired as a supervisor are learned in most cases. There are a few of us that have that natural ability, but for the most part most supervisors are promoted because they were super-workers not because of their ability to supervise.

As a supervisor you need to find out what motivates an employee. Remember managers do not motivate employees. Motivation is something that a person has within him - he brings it with him. A manager can stimulate motivation through training, planning methods and rewarding accomplishment.

Last year the Oklahoma Forestry Division spent $27,283.57 on a weed control program. Of the total cost $18,241.71 was labor and $9,041.86 was spent on chemicals:

Table I. Three Year Cost Data of Oklahoma's Weed Control Program

	Total Hrs. & Costs By Year		
	FY83	FY84	FY85
Labor (Hrly) on chemical control	1,284.5	1,691	1,530.25
Labor (Hrly) on hand weeding	3,255	2,988.5	2,862
Total Hours	4,539.5	4,679.5	4,392.25
Labor ($) on chemical control	7,920.78	8,987.28	8,216.26
Labor ($) on hand weeding	11,359.95	10,448.58	10,025.45
Total ($) of labor ($8/hr. for Sr. Technician and $3.35/hr. temporary labor)	19,280.73	19,435.86	18,241.71
Chemical Cost	5,334.73	9,109.00	9,041.86
Total Cost	24,615.46	28,554.86	27,283.57
Total Seedling Production	1,562,300	1,191,650	1,685,600
Cost Per Seedling	.01575	.02396	.0162

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[1] Paper presented at the Intermountain Nurseryman's Association Meeting, Fort Collins, CO, August 13-15, 1985.

[2] A.K. Myatt is Area Forester for the Oklahoma Forestry Division. Mike Vorwerk is Nursery Manager for the Oklahoma Forestry Division.

The following information is a comparison of hand weeding vs. hand weeding and chemical control on 25 acres based on data from a 1981 study at the Norman Nursery done by Dr. Larry Abrahamson, SUNY.

Table II.

Hand Weeding Only	$133,000.00/yr (est)	
Chemical Control + Hand Weeding	27,283.57/yr	(Actual cost for 1985)
Savings/Year	105,716.43	

We like to think the money was well spent. However, we will continue to work closely with the staff in the manner I have discussed to help each individual become more informed to further reduce costs, both in labor and chemicals.

I feel that management should behave as if employee development is the lifeblood of the organization. This is not to suggest that employee development is of more importance than operations or accounting efforts. It is rather to say that the growth of the organization is dependent upon the growth of its employees.

One observation that I might mention is, when the human resouce is poorly utilized so is the equipment and the supplies, (in this case chemicals), that are purchased to do the job. This generally means that both labor and materials cost more to complete the project in a less than acceptable manner.

Another area that is important to everyone is: Why have an effective weed control program? Each individual on the team needs to know and appreciate what the purpose of what they are doing is all about. Or, why should we bother?

An effective weed control program will help:

A. Reduce fertilizer costs.
B. Reduce competition in the seed bed yielding an increased quality crop.
C. Increase survival of the germinating seed.
D. Reduce the number of cull seedlings at the time of harvest.
E. Allow more effective use of irrigation water.
F. Reduce weed seed sources for future crops.
G. Decrease problems with lifting and grading seedlings.
H. Increase esthetics, improve attitudes, organization and funding.

Solving a complex problem like weed control requires a wide range of technical methods and cultural practices. The following are methods and techniques utilized at the Oklahoma State Nursery.

> Treflan is applied to all areas that are planted to seedling crops except for a few non tolerant species. The herbicide is applied 2-3 weeks prior to planting.
>
> Pre-emerge herbicides such as Mowdown, Devrinol, Dacthal, Goal and Ronstar are applied over the tops of the seedlings on all species grown. The herbicides are applied with tractor mounted spray tanks and the granular forms are applied with a Gandy fertilizer spreader.

Mechanical weed removal methods are required on a small scale, because the pre-emerge herbicide will not control all the weeds.

> Hoeing: Hoeing is used on some weed crops in the more open grown species and along the outside edge of the seedling beds. Triangular shaped hoe blades seem to work the best.
>
> Hand pulling: The weeds are removed from the ground by utility knives with curved blades.

If the weeds have started to seed out, they are bagged up and removed from the field.

Drop tubes have been developed on a tractor mounted spray boom to spray pre-emerge or contact herbicide along irrigation lines. The boom can easily go over the top of the riser while the drop tube applies the herbicide from the proper height With slight modifications the drop tubes could be used to spray aisles on tall species.

A tractor mounted spray tank was built for spraying Roundup herbicide. The tank has a center and side mounted boom. The tank also has a hand gun spraying open areas such as along windbreaks, fronts of beds or along irrigation lines. It can also be used for spot spraying.

Hand held spray tanks are used extensively for weed control. The 1½ - 2 gallon tanks can easily be carried by the employee. Roundup is used in the tanks. The tanks have long wands so the employees can easily spray weeds between the seedlings. Cones are placed over the nozzles so the herbicide is targeted just to the weeds.

Weedwicks are also extensively used for weed control. Roundup at a 33% rate is used in the wicks. The wicks can be used in tight places between see lings. The sponge type weed wick head seems to work best. This type gives the best coverage and eliminates dripping.

A purple dye is used in the hand sprayers and weedwicks. The dye helps with visual metering of the Roundup. It was specifically developed to be mixed with Roundup. The dye is produced by Becke Underwood in Ames, Iowa.

A ½" layer of sawdust mulch is applied to several species of hardwoods during mid-summer. The sawdust helps to moderate the soil temperature and has some weed control benefits. The sawdust is applied with a manure spreader when the seedlings are 6-8" tall. This practice does not work well on the conifers because it has a tendency to bury them, the sawdust won't sift through the needles. The sawdust does not affect the fertilizer requir ments of the seedlings.

Cover crop is planted on all fallow areas. The cover crop reduces the weed crop that might come in, prevents wind erosion and increases the organ ic matter. Sudan is planted in the spring and wheat is planted in the fall.

Weedeaters are used to control the weeds from seeding out on weeds around the complex, windbreaks and other areas that can't be mowed or sprayed.

Methyl Bromide fumigation is used on a limited basis at the Oklahoma State Nursery for weed control.

In the past several years with increased costs in labor, herbicides have been the main focal point. The Oklahoma Forestry Division started its herbicide program in the fall of 1977. Dr. Larry Abrahamson, SUNY, under funding from the U.S. Forest Service drew up a three year program to test and register chemicals for nursery use. Larry has continued with the Oklahoma Forestry Division under contract with SUNY. The following summary in Table III. shows what herbicides are currently operational in the Oklahoma Nursery:

Table III.
Herbicides Applied at the Oklahoma Nursery

Herbicides	Species	Rate (Lbs. AI./AC.)
Mowdown/Devrinol Tank Mix	All conifers, Lacebark Elm, Arborvitae, Russian Olive, Autumn Olive, Green Ash and Baldcypress	3.0/1.0
Goal	All conifers: Loblolly, Shortleaf, Scotch, Austrian, Ponderosa and Virginia Pines, Red Cedar and Arborvitae	.5
Dacthal/Devrinol Tank Mix	Euonymus, Hackberry, Multiflora Rose, Redbud, Catalpa, Sand Plum, Silver Maple, Osage Orange, Mulberry, Black Walnut, Pecan and Bur Oak	10.5/1.0
Ronstar or Treflan, Granular	Black Locust	1.0
Treflan (Pre-Plant)	All species except Euonymus, Hackberry, Lacebark Elm, Sand Plum, Sycamore, Catalpa and Silver Maple	1.0
Mowdown/Devrinol Tank Mix or Goal	Irrigation lines and along windbreaks	3.0/1.0
Roundup	General Use	2-3 oz/gal.

Dr. Larry Abrahamson has continued his research and the following is an outline of the current work that he is doing (Table IV). He has worked closely with the Oklahoma Forestry Division over the past 8 years to develop the herbicide program we have today. Thanks to everyones efforts and his direction and research we have saved thousands of hours in labor and increased the quality of our seedlings.

A quick look into the future shows that continued work needs to be done in finding chemicals that can be applied to some of the sensitive hardwoods.

Table IV.
Herbicide Research 1985, Oklahoma Nursery
Coordinated Through State University, New York

Species	Herbicide Tested	Rate (Lbs AI./AC.)
Pecan	Devrinol (50W)	1.5
	Mowdown (80W)	3.0
	Caparol (80W)	1.0
	Dacthal (75W)	10.5
	Devrinol/Mowdown (Tank Mix)	1.0/3.0
Sycamore, Catalpa, Lacebark Elm and Redbud	Enide (90W)	4.0
	Treflan (4EC)	.75
	Dacthal (75W)	10.5
	Devrinol (50W)	1.5
	Ronstar (2G)	1.0
	Caparol (80W)	1.0

Each chemical was tested post seed, post germination and post seed plus post germination. Each was tested at 1X and 2X rates.

It is also important to have several herbicides for each species so that a rotation can be set up. This will reduce the chances of different weed species becomming resistant to the chemicals.

To increase the effectiveness and versitility of chemicals, "underleaf spraying equipment" needs to be perfected and utilized. This will allow us to place a wider varity of chemicals on specific areas of the plants, weeds, or just on the soil. This should help:

A. Reduce hand weeding costs, or make them nonexistant.
B. Reduce the cost of chemicals, in that the spray is directed to areas where it is most effective.
C. Reduce damage to the plants from stunting or decreased vigor.
D. Help apply chemicals to sensitive plants that we currently do not have control methods for.
E. Allow more than one cultural practice to be carried out at one time. ie. underleaf spraying and cultivation, or underleaf spraying and fertilization.
F. Allow more than one chemical to be sprayed at a time (example - spray a contact such as roundup as needed along with a pre-emergent).

References

Broadwell, Martin M. 1979. Moving up to Supervision. 163 p. CBI Publishing Company, Boston, Mass.

O'Boyle, Thomas F. Loyalty Ebbs at Many Companies as Employees Grow Disillusioned. The Wall Street Journal July 11, 1985, 25 p.

Waters, Maureen. Motivation: Tapping the inner drive. Grounds Maintenance. March 1985.

Nursery Research: A Practical Approach[1]

G. Bruce Neill[2]

Abstract.--A summary is given of research activities being carried out at the PFRA Tree Nursery, Indian Head, Saskatchewan. Main areas of investigation include propagation, tree improvement, weed control, soils, entomology and pathology.

INTRODUCTION

The PFRA Tree Nursery has produced and distributed over 450 million seedlings since its establishment in 1902. The mandate of the Nursery remains much the same today as when it started, that is, to provide trees for shelter to farmers in the Canadian prairie provinces. Currently, approximately 25 species are produced, comprised of both coniferous and deciduous stock. Almost half of our yearly production is one specie, namely caragana (Caragana arborescens). The trees are used as farmstead shelterbelts for protection of yards, as field shelterbelts for soil erosion control and snow management, and as roadside belts for snow control.

Almost 40 years ago, the Nursery established a research component responsible for conducting studies on tree breeding, physiology and pest control. Since that time the research section has undergone a number of changes. Today this section is composed of five units, namely, Propagation, Soils, Herbicides, Entomology and Shelterbelt Studies. There are a total of eight full time and six seasonal or casual personnel in the section. This represents about 16 percent of the total allotment for the Nursery. The mandate of the group is to solve the problems associated with growing trees on the prairies and to determine the effects of these trees on prairie agriculture. Each year numerous practical studies are completed and reported in our Annual Report. Recommendations are implemented by our Production and Extension Sections.

Along with the research mandate, the Investigation Section is also responsible for overseeing most technical operations on the Nursery. For example, herbicide, insecticide and fungicide applications are supervised and/or conducted by Investigation personnel. Implementation of test results therefore, becomes fairly straightforward.

Examples of areas of research being conducted by each of the five units in the Investigation Section follow:

Propagation

Bill Schroeder is in charge of both the Propagation and Soils Units. Our Propagation technician is Dan Walker. The Propagation Unit is the largest group with the greatest diversity of studies. Examples of trials conducted in 1985 include such things as dates, rates and depth of sowing seed, effects of mycorrhizae, root wrenching treatments, fall vs spring sowing, propagation techniques for poplar cuttings, evaluation of seedling maturity, ethylene adsorbant for seedling storage, freezer storage techniques, green ash provenance trials, USSR pine breeding trial, USSR Siberian larch provenance trial, and packing material tests. Other areas of interest include seed storage, seed stratification, chemical fruit drop, chemical defoliation, container culture technique and others. For details on these and many other related topics, refer to our Annual Report.

Soils

The Soils Unit is responsible for providing service support to the Production Section by conducting soil analysis of all fields. Our Soils technician is John Cruickshank. Recommendations are provided on the basis of fertility trials conducted at the Nursery. Irrigation scheduling has also been reviewed with hopes of implementing a more precise system.

Herbicides

Bruce Neill is in charge of both the Herbicide and Entomology Units. Our Herbicide technician is

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[1] Paper presented at the Intermountain Nurseryman's Meeting (Colorado State University, Fort Collins, August 13-14, 1985).

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Lyle Alspach. Current studies include screening herbicides for preemergence weed control in sowings of Colorado spruce, Scots pine, white spruce, honeysuckle, green ash and caragana, and in poplar and willow hardwood cuttings. Post-emergence weed control in villosa lilac and caragana is also being persued. Herbicides for use in newly planted and established shelterbelts are continually being screened. The Nursery now has herbicide recommendations for over 70 percent of our annual production and has one to four people involved in herbicide applications throughout the growing season.

Entomology

Don Reynard is the technician working in the Entomology-Pathology Unit. Studies dealing with pesticide efficacy, life history, pheromones and fungicide efficacy are conducted yearly. Currently, much work is being done on pheromones for monitoring and control of the cottonwood crown borer (*Sesia tibialis*), and the spring cankerworm (*Paleacrita vernata*). Insecticide trials are conducted on pests as they arise. In 1985, insecticides were tested for control of the cottonwood crown borer, spruce budworm (*Charistoneura fumiferana*), blister beetles (*Lytta* spp.) and the willow shoot sawfly (*Janus abbreviatus*). Fungicide trials are conducted for control of storage molds, and poplar cuttings diseases. The Saskatchewan Dutch Elm Disease survey is also supervised by the Entomology Unit.

Shelterbelt Studies

John Kort heads this new unit which started in 1984. Studies will be conducted to support our Extension Section, who are responsible for promoting the use of shelterbelts on the prairies. Effect of shelterbelts on microclimate, crop yields, snow distribution and other effects will be of major concern. Potatoes, canola, safflower and wheat are currently being evaluated for their response to shelter. Various shelterbelt species and designs are also being tested for their potential in a soil conservation system.

CONCLUSION

All studies conducted at the Nursery have a practical origin. Through the last 40 years we have been able to build up a technical support staff for our Production and Extension Sections. Although our trials are aimed at solving our own problems, results often apply to other nurserymen. We encourage others to tour our operation and to call on us for advice. Yearly summaries of all studies can be found in our Annual Report which can be obtained by writing the author.

Soil Compaction: Effects on Seedling Growth[1]

Steven K. Omi[2]

Abstract.--The degree to which a compacted soil affects seedling survival or growth varies according to soil texture, organic matter, moisture content, tree species, and degree of compaction. Soil compaction generally restricts root growth and can inhibit shoot growth. In nurseries, compaction may be rare above the 15-cm depth because nursery soils are cultivated each year; however, below 15 cm compaction is relatively common, and is especially noticeable when drainage is impeded for long periods. The machinery used to manage the crop, the ability to control irrigation and fertilization, and the alternatives for tillage are all important aspects of nursery soil management affecting soil compaction.

INTRODUCTION

This report is the result of a need, expressed by Nursery Technology Cooperative (Oregon State University) members, in particular seedling users, for a literature search on the effects of soil compaction on seedling growth. However, compaction is also of concern to nursery personnel: in an OSU Nursery Survey, compaction was considered a problem by 62 percent of the nurseries surveyed and, relative to all other soil-related problems, was ranked first or second in importance by 24 percent of respondents (Warkentin 1984). Although soil compaction in agricultural crops has been extensively studied (Rosenberg 1964; Greacen and Sands 1980), little information has been published regarding the problem of compaction of forest nursery soils. It is the purpose of this report to review the effects of compaction on soil and seedling growth.

COMPACTION DESCRIBED

Simply stated, soil compaction is a decrease in volume for a given mass of soil (McKibben 1971) as a result of an applied load, pressure, or vibration. It produces rearrangement of soil aggregates and particles, and changes in soil properties (typically, increased bulk density or soil strength, or decreased porosity). Because compaction status of a soil influences air, water, and temperature relationships, it can affect all stages of crop production (McKibben 1971). The energy required to compact soil comes from a variety of sources including rainfall, irrigation spray, foot traffic by animals and people, plant roots, and weight of the vegetation and soil; a significant compacting force is produced by the machinery used to manage and harvest the crop (Greacen and Sands 1980). Whatever the cause, soil compaction may be characterized via several means, including bulk density, soil strength, permeability, and visual observations.

Bulk Density

Bulk density (usually expressed in grams per cubic centimeter) is found by determining the dry weight of soil occupying a known volume (solids plus pore spaces).[3] Bulk-density measurements are commonly used because of their relative ease of sampling, insensitivity to moisture, and known relationships with tree growth (McNabb 1981). The bulk density of most nursery soils is approximately 1.3 g/cm^3, ranging from 0.9 g/cm^3 in sands to 1.6 g/cm^3 in clay loams (Day 1984).

Generally, four methods are used to measure bulk density: core, excavation, clod, and radiation. In the core method, soil cores are collected in a sampler of known volume. This relatively simple procedure does not require complex equipment and leaves the natural soil structure of the extracted core intact so it can be used for other measurements (Adams 1983; Flint and Childs 1984). However, the procedure is time consuming, results can be difficult to obtain in the field, and the presence of large rocks and root fragments can bias the sample (Flint and Childs 1984). In the excavation method, the mass of soil excavated from a hole is divided by the volume of the hole (measured by filling the hole with material of known density or volume, such as water or sand). Like the core method, the excavation method is relatively simple and is suitable for soils having larger coarse fragments. Its disadvantages include the time lag between field sampling and results, accuracy in determining the volume of the excavated hole, and disturbance of the soil sample such that it cannot be used to assess other soil properties (Blake 1965; Adams 1983). In the clod method, clods are removed, weighed, coated with a water-repellent material (such as paraffin), and then immersed in water to determine clod volume. This simple procedure is useful for hard soils; additionally, the clods can be preserved for other measurements as long as the test is done carefully, to maintain clod structure. However, this method is time consuming; and potential bias exists because of the tendency to select samples which are firm enough and of adequate size (Freitag 1971) and because the measurement can exclude the pore spaces between clods (Adams 1983; Flint and Childs 1984).

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[1] Paper presented at the 1985 Intermountain Nurseryman's Association Meeting. [Fort Collins, Colorado, August 13-15, 1985].

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[3] Particle density, another expression for describing soil weight, is the dry weight of soil per solid (excluding pore space) volume.

Whereas the core, excavation, and clod methods disturb the soil, nuclear density probes can nondestructively sample for bulk density. The ability of radioactivity to penetrate the soil reflects the density of soil particles; as soil density increases, the ability to penetrate decreases (Freitag 1971; Adams and Froehlich 1981). The advantages of this method are that many measurements can be taken rapidly in the field, soil disturbance is kept to a minimum, and the same sampling site can be measured more than once. Additionally, since changes in water content cause changes in density, nuclear probes can be used to assess seasonal changes in water content. The disadvantages include the need for expensive equipment, calibration curves to convert counts of radiation to bulk density, and minimizing human exposure to radiation. However, recent improvements in radiation technology make this a worthwhile method for land managers to consider as an alternative to or in combination with conventional techniques.

Although soil bulk density is the most frequently used measurement to assess compaction, it is only an indirect measure of how change in soil physical property affects root growth (McNabb 1981) and gives little information on pore-size distribution or particle arrangement (Freitag 1971). Soil strength (mechanical resistance) and aeration, two significant factors limiting growth in compacted soils and whose effects are often difficult to separate (Warkentin 1984), are the main physical properties affected by increases in bulk density.

Soil Strength

Soil strength refers to the mechanical resistance of soil to an applied force. Shear tests (measuring the torque required to shear the soil along the surface) and penetration tests (measuring the weight required to push a tip, plate, or footing of some type into the soil to a certain depth) can assess soil strength with simple procedures; large areas can be measured quickly, and because soil is only minimally disturbed, several measurements can be taken near the same sampling point (Freitag 1971; Adams 1983). Although both shear and penetration tests seem equally suitable for assessing soil compaction (Freitag 1971), it is important in both cases to standardize procedures and equipment so that results can be reproduced. Soil properties such as moisture or texture (Adams 1983; Warkentin 1984), shape of the penetrating or shearing element, and rate at which elements are advanced into the soil all can affect results (Freitag 1971).

Soil strength typically increases when a soil is compacted, and strength tests have been significantly related with bulk density measurements. Gifford et al. (1977) found soil-core bulk density to be significantly correlated with pocket penetrometer resistance and proving ring penetrometer resistance. Penetrometer resistance may be a better indicator than soil bulk density of seedling performance in compacted soils (Zisa et al. 1980). Several studies have shown that resistance to a metal probe correlates well with soil resistance to root penetration (Gooderham and Fisher 1975; Sands et al. 1979; Zisa et al. 1980).

Permeability

Because compaction alters soil porosity, it can be assessed by the ability of a liquid or air to pass through the pore spaces. An increase in bulk density generally lowers macroporosity (the number of macropores, or noncapillary pores through which water and gas usually flows rapidly) and reduces permeability (Howard and Singer 1981).

In liquid permeability tests, a known amount of fluid (e.g., water) is applied to a soil core or surface and its infiltration rate assessed. However, liquid permeability measurements are not easily made and can be time consuming. Although a strong laboratory relationship has been shown between fluid conductivity and compaction variables, insufficient field testing increases the difficulty in assessing the operational usefulness and accuracy of such a test (Freitag 1971).

In air permeability tests, a known pressure of gas is applied to the soil surface and the backpressure measured (in pounds per square inch, or kilopascals). Air permeability tests are relatively quick and easy and only minimally disturb the soil. However, because the test apparatus must be sealed against air losses, the contact zone between soil and test instrument must be sufficiently leakproof. Moreover, the optimum condition for such tests is a perfectly dry soil (e.g., dry sand) because the presence of water in pore spaces complicates the evaluation of test results: a soil with different water-retention abilities can be expected to produce different air permeameter measurements (Freitag 1971; Gifford et al. 1977). Unfortunately, the optimum dry condition is not usually attained in practice, so the resulting values must be appropriately calibrated (Freitag 1971; Adams 1983).

Visual Observations

Of all techniques for assessing soil compaction, visual observations may be the most rapid and least expensive. Visual evidence includes reduced drainage because of reduced soil permeability, difficulty in penetrating the soil surface (e.g., with a shovel) especially when dry, soil structure changes (e.g., a compacted soil when dry will be brittle and often layered, a noncompacted soil crumbly and granular), and good initial germination followed by stunted plant development later on (Freitag 1971; Adams and Froehlich 1981). However, visual observation is difficult to use in monitoring less than severe compaction levels and, of all techniques, is the most subjective and least quantitative (Adams 1983).

RELATIONSHIPS BETWEEN SOIL FACTORS AND COMPACTION

A compacted soil reflects conditions of increasing bulk density and soil strength, and decreasing porosity and infiltration. Most of the loss in porosity is in the macropores, where air and water movement is normally the least restricted (Greacen and Sands 1980; Adams and Froehlich 1981; Warkentin 1984). However, the degree to which compaction affects soil properties will be influenced by texture, organic matter, and soil moisture.

Texture

Texture refers to the relative proportions of sand, silt, and clay in a particular soil. Grain-size distribution and composition affect the resistance of soil to compaction. Soils with a narrow range of grain sizes resist compaction reasonably well, but soils with a wide range of grain sizes are more susceptible because the smaller grains move into the pore spaces between the larger grains, thereby increasing the packing of soil particles (Lull 1959; Bodman and Constantin 1965; Warkentin 1971; Froehlich 1974).

Organic Matter

Soil resistance to compaction is significantly influenced by organic matter content (Greacen and Sands 1980). Organic matter stabilizes aggregates and alters aggregate strength (Warkentin 1984).

Benefits of organic matter have been observed in both laboratory and field tests. Estimates of bulk density (0.54 to 0.63 g/cm^3) in the surface 20 cm of soil of an old plank road were found to be low because of high organic matter content (Power 1974). Sands et al. (1979) reported that the degree of soil compaction changed with differences in organic matter content under a given constant applied load, bulk density generally decreasing with increasing organic matter content under unsaturated conditions. Yet extremely high levels of organic matter may render soils susceptible to disturbance because of their low soil strength (Froehlich and McNabb 1983).

Soil Moisture

The most significant factor influencing soil compaction is moisture level during the compaction process (Warkentin 1984). In general, resistance to compaction is large when soils are dry because little lubrication (for particle rearrangement) is provided by thin water films (Lull 1959). As moisture content increases, lubrication increases and soil becomes easier to compact. For example, Eavis (1972) found that penetrometer resistance decreased as moisture content (at the time of compaction) of a sandy loam increased. In an unsaturated sandy soil, bulk density increased as applied load (range 60 to 360 kPa) increased (Sands et al. 1979); at the lightest load, it was ~ 1.3 g/cm^3, at the heaviest 1.4 g/cm^3. But in a saturated soil, even slight applied loads (60 kPa) resulted in bulk densities > 1.5 g/cm^3.

However, bulk density due to compaction does not continue to increase as water content increases. Instead, a water content is reached at which the maximum number of smaller particles are forced between the coarser grains and the remaining spaces filled with water (Lull 1959; Hatchell et al. 1970). Beyond the water content at which maximum bulk density is attained, compaction decreases and the potential for soil puddling (destruction of soil structure) increases (Lull 1959; Sidle and Drlica 1981; Warkentin 1984); upon drying, such soils can be left highly compacted.

The influence of water content on compaction is also affected by soil texture. For example, in laboratory tests, sandy clays may be compacted to 1.7 to 2.1 g/cm^3 at only 8- to 15-percent moisture, clays to 1.5 to 1.7 g/cm^3 at 20- to 30-percent moisture (Froehlich 1973). Similarly, Bodman and Constantin (1965) showed that as clay content increased, the percent water content at which maximum bulk density was attained also increased. Warnaars and Eavis (1972) found that penetrometer resistance in fine sands decreased as moisture content increased, but that in coarse sands was relatively unaffected by moisture content. No significant difference in penetrometer resistance at a constant bulk density (1.45 g/cm^3) was found for a sandy soil over moisture contents ranging from 2 to 12 percent (Sands et al. 1979). It is important to emphasize that the previously mentioned results all were from laboratory tests and that, irrespective of the degree of sensitivity to moisture and/or texture, a soil may be susceptible to significant compaction over a wide range of moisture contents in the field (Froehlich and McNabb 1983).

EFFECTS OF COMPACTION ON POROSITY AND DRAINAGE

Porosity

Regardless of the mechanism, the net effect of soil compaction will be reduced air porosity (Grable 1971). Total porosity is defined as the ratio of pore-space volume to total volume (Harris 1971). Of perhaps greater significance than the decrease in total porosity is the change in pore size distribution. Most of the loss in porosity will be in the macropores, and the proportion of micropores will increase (Harris 1971; Greacen and Sands 1980; Adams 1983; Warkentin 1984). Foil and Ralston (1967) showed that increasing bulk density from laboratory compaction on a loamy sand (1.07 to 1.33 g/cm^3), loam (1.06 to 1.38 g/cm^3), and clay (1.31 to 1.49 g/cm^3) corresponded to approximately 64- to 69-percent reductions in macroporosity. Under field conditions, vehicular-induced compaction which increased bulk density from 0.90 to 1.20 g/cm^3 reduced macropore volume by 50 percent for a range of forest soils (Hatchell et al. 1970). Campbell et al. (1973) found a 28- to 72-percent decrease in macroporosity in logged areas compared to undisturbed plots, depending on the degree of disturbance.

Drainage

The degree to which compaction affects drainage or infiltration of water is related to the changes in soil structure brought about by the compactive effort. Because compaction generally reduces the proportion of macropores and increases the proportion of micropores, water movement becomes restricted and drainage can be impeded.

Significant relationships have been found among increasing bulk density, decreasing infiltration, and decreasing porosity (Lull 1959). Decreased infiltration rates in compacted soils have been reported after logging (Steinbrenner 1955; Steinbrenner and Gessel 1955b; Perry 1964; Hatchell et al. 1970) and as effects of human and animal traffic (Lull 1959). Reduced infiltration and impeded drainage can lead to surface runoff--excess rain may cause waterlogging and associated aeration problems in the rooting zone (Gifford et al. 1977; Greacen and Sands 1980; Sidle 1980). In addition, compacted soils have low temperatures in spring (Gill 1971) and, because of reduced drainage, remain wet and do not warm as fast as noncompacted (i.e., well-drained) soils.

EFFECTS OF COMPACTION ON SEEDLINGS

The abundance of literature addressing plant responses to changing soil conditions resulting from compaction has not always led to the same conclusions (Lull 1959; Rosenberg 1964; Trouse 1971; Greacen and Sands 1980). The contradictory effects reported are probably due to the complexity of interactions among soil strength, aeration, moisture, nutrient supply, and species. In their review of soil compaction, Greacen and Sands (1980) indicated that of 142 studies they surveyed between 1970 and 1977, 82 percent showed reduced crop yield due to compaction, approximately 8 percent increased yield, 6 percent both reduction and increase, and 4 percent no effect. Of these studies, only 18 percent dealt with tree species, but reduced growth due to compaction has been reported for several economically important tree species including Pinus radiata, Pinus elliottii, Pinus taeda, Pinus ponderosa, Pinus nigra, Picea abies, and Pseudotsuga menziesii.

Seedling Survival

Effects of compaction on seed germination or seedling survival have varied. For Pinus taeda seed sown on a loamy sand, loam, and clay, compaction treatments did not significantly affect germination (Foil and Ralston 1967); however, survival percentages were uniformly reduced on compacted soils, the lowest generally on clay. Likewise, Hatchell (1970) found that over a variety of soil types, a 16-percent average increase in bulk density (1.26 to 1.46 g/cm^3) due to compaction treatments corresponded to a 24-percent decrease in P. taeda seedling establishment; on a clay loam, though, compaction had little effect. For Pinus rigida, Pinus nigra, and Picea abies, Zisa et al. (1980) reported that seedling establishment was generally > 75 percent on a sandy loam, regardless of compaction intensity (1.2, 1.4, 1.6, and 1.8 g/cm^3); on a silt loam, only soil compacted to 1.8 g/cm^3 significantly reduced seedling establishment.

The previously cited results were from greenhouse or shade house experiments. Yet several reports of seedling establishment in areas disturbed or compacted due to logging present similar findings. Steinbrenner and Gessel (1955a) report reduced coniferous seedling establishment for naturally regenerated skid roads compared to cutover tractor-logged areas. Duffy and McClurkin (1974) analyzed several soil characteristics on both failed and successful P. taeda plantations to determine characteristics useful for site classification. Bulk density was the most important: plantation failure was predicted on sites where bulk density exceeded 1.45 g/cm^3. There are, however, several instances in which soil compaction due to skidding or logging has had no effect on conifer survival from the first or second (Youngberg 1959; Campbell et al. 1973) through the fourth (Hatchell 1981) growing season after planting.

Root Growth

Root growth is generally restricted as soils become more compact. For example, Heilman (1981) found that length of primary root penetration of Pseudotsuga menziesii seedlings decreased 71 to 87 percent as bulk density increased from 1.38 to 1.76 g/cm^3 (fig. 1) and that 27- to 30-percent pore space[4] prevented rooting of seedlings 35 to 45 days from germination in loam and sandy loam. Hatchell (1970) showed that for Pinus taeda seedlings growing in a range of soil types, shoot to root ratio (dry weights) after the first growing season was negatively related to macroporosity, suggesting that the proportion of roots increased as air space increased.

The degree to which compaction affects root growth depends on species (Minore et al. 1969; Singer 1981; Halverson and Zisa 1982), soil type (Hatchell 1970; Singer 1981), and magnitude of compactive effort, as well as on environmental factors (table 1). Halverson and Zisa (1982), among others, found that of several growth variables measured, root penetration depth (of three conifer species) was the most responsive to compactive effort. Further, whereas effects of compaction on root dry weights have varied (Foil and Ralston 1967; Hatchell 1970; Singer 1981; Tworkoski et al. 1983), reductions in root penetration > 50 percent are repeatedly noted (table 1). Compaction is also likely to alter root distribution in soil. Decreases

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[4] Percent pore space = 100 - (bulk density/particle density) x 100.

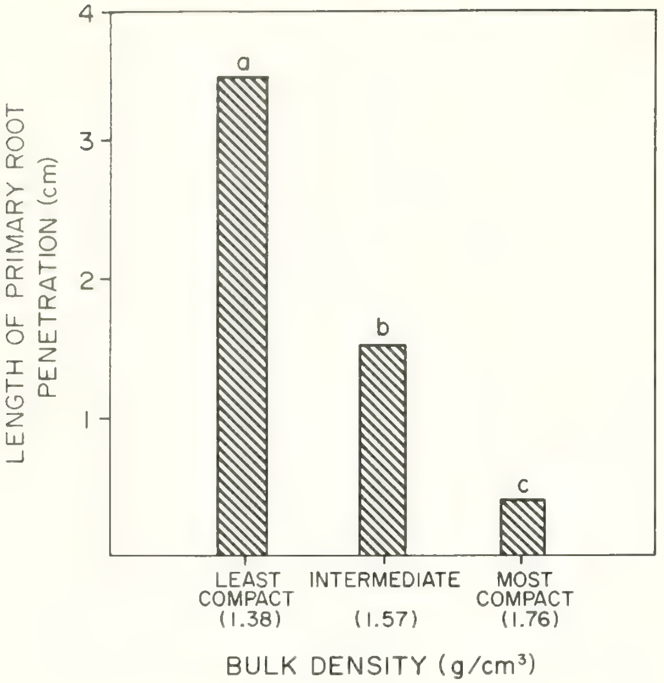

Figure 1.--Length (averaged over three soil types) of primary root penetration of *Pseudotsuga menziesii* in soils compacted to three bulk densities (adapted from Heilman 1981). Means not followed by the same letter are significantly different at $p \leq 0.05$.

in branching (*Pseudotsuga menziesii*, *Tsuga heterophylla*--Pearse 1958), and total root number and fine roots (*Pinus ponderosa*, *Pseudotsuga menziesii*--Singer 1981) have been observed for species in compacted soil, although lateral roots (*Pinus taeda*--Foil and Ralston 1967) and fine roots (*Fagus* spp.--Hildebrand 1983) have, in some cases, proliferated for trees growing in compacted soils.

In a fine-textured, poorly drained, compacted soil, oxygen deficit can limit root growth; but in a coarse-textured, well-drained compacted soil, or when seedling growth is not limited by lack of water or reduced aeration (Sands and Bowen 1978), reduced root growth or penetration can be related to differences in soil strength (Heilman 1981). Often, however, the factors responsible for poor root growth in compacted soils interact and are difficult to separate. Hatchell (1970) concluded that reduced root growth of *Pinus taeda* in compacted soils could result from low oxygen supply to roots and high resistance to penetration. Eavis (1972) studied the interaction of mechanical impedance, aeration, and moisture availability for pea growth in a sandy loam soil. Under drier conditions, reduced root growth was due primarily to mechanical resistance if bulk density was high but to moisture stress if bulk density was low. Under wetter conditions, reduced root growth could be due to poor aeration and resistance to penetration in compacted soil but primarily to poor aeration in loose, wet soil.

Shoot Growth

As with root growth, the effect of compaction on shoot growth cannot always be predicted due to the complex interactions among soil physical characteristics and species. If air, water, and nutrients are in sufficient supply and if root length is adequate to meet shoot requirements, poor root development in compacted soils can still support good shoot growth (Hatchell 1970; Greacen and Sands 1980). In some cases, compaction can increase the diffusion of ions (e.g., phosphorus) and improve nutrient uptake; however, under other circumstances, compaction can be detrimental to nutrient status and reduce the mineralization of nutrients from soil organic matter (Kemper et al. 1971; Greacen and Sands 1980). Both large (Forristall and Gessel 1955; Minore et al. 1969) and small (Zisa et al. 1980) effects of compaction on shoot growth have been observed in conifers.

Young (< 2 years) seedling shoot growth varies in response to compaction in laboratory experiments (table 2). Bulk-density increases of 7 to 20 percent have corresponded to reductions of 16 to 56 percent and 11 to 38 percent in shoot dry weight and total height, respectively (Minore et al. 1969; Hatchell 1970; Sands and Bowen 1978). But there are also instances in which increasing compaction has not affected shoot dry weight, shoot growth, or total height (Minore et al. 1969; Heilman 1981; Singer 1981; Tworkoski et al. 1983) or even led to increased shoot growth or shoot dry weight (Trujillo 1976; Singer 1981). These inconsistencies show that compaction effects on young seedlings depend on the interaction of species, age, soil texture, compaction severity, and other soil physical characteristics.

Nearly all field studies relating tree response to compaction have pertained to growth after logging (table 3). In general, tree growth in compacted zones has declined relative to control or undisturbed areas. Estimated reductions in height growth or total height have ranged from 6 to over 50 percent (table 3). Over a variety of tree species, soil types, and field locations, Froehlich and McNabb (1983) found a generally linear relationship between increased soil density and reduced seedling height growth.

THE COMPACTION PROBLEM IN TREE NURSERIES

Despite the concern for soil-related problems, very little research has been done on compaction problems in forest-tree nurseries. Lowerts and Stone (1982) studied the effect of an existing compacted soil layer on nursery growth of *Liquidambar styraciflua*. After one growing season, seedlings were tallest in nursery plots where bulk densities were < 1.7 g/cm^3 in the surface 39 cm of soil. Furthermore, a significant negative correlation was found between seedling height and bulk density at the 26- ($r = -0.66$), 39- ($r = -0.86$), and 52- ($r = -0.65$) cm depths. Minko (1975) reported of a compacted nursery subsoil (bulk density ~ 1.5 g/cm^3 at the 20- to 40-cm depth) which impeded *Pinus radiata* tap root penetration. Yet the density (1.2 to 1.4 g/cm^3 in the top 18 cm of soil) of the able 1.--Effect on roots as bulk density increased, over a variety of species and soil types, from selected laboratory studies.

eference	Species [approximate age]	Soil type	Bulk density values	Effect on roots as bulk density increased
			--- (g/cm^3) ---	
eilman (1981)	*Pseudotsuga menziesii* [35 to 45 days]	Loam, sandy loam	1.38-1.57	54% reduction, length of primary root penetration
			1.38-1.76	87% reduction, length of primary root penetration
workoski et al. (1983)	*Quercus alba* [40 days]	Silt loam	1.0-1.2-1.5	55% reduction, tap root length 59% reduction, primary root number No effect, root dry weight
earse (1958)	*Pseudotsuga menziesii*, *Tsuga heterophylla* [56-90 days]	Sandy loam	0.59-0.84-1.02	Shorter, stockier, thicker, not as profusely branched
isa et al. (1980)	*Pinus rigida*, *Pinus nigra*, *Picea abies* [120 days]	Silt loam	1.2-1.4	~ 75% reduction, depth of root penetration
			1.2-1.8	~ 80% reduction, depth of root penetration
		Sandy loam	1.2-1.4	No effect, depth of root penetration
			1.2-1.6	~ 50% reduction, depth of root penetration
			1.2-1.8	~ 80% reduction, depth of root penetration
ands and Bowen (1978)	*Pinus radiata* [150 days]	Sand	1.35-1.48	No effect, main root length or root dry weight
			1.35-1.60	73% and 46% reductions, main root length and root dry weight, respectively
atchell (1970)	*Pinus taeda* [150 days]	Loamy sand	1.26-1.46	55% reduction, root dry weight
		Loam	1.30-1.47	40% reduction, root dry weight
		Silt loam	1.34-1.62	50% reduction, root dry weight
		Sandy clay loam	1.14-1.28	29% reduction, root dry weight
		Clay loam	1.04-1.12	17% reduction, root dry weight
oil and Ralston (1967)	*Pinus taeda* [1 year]	Loamy sand, loam, clay	0.8-1.4	~ 64% reduction, root length[1] ~ 80% reduction, root dry weight[1]
rujillo (1976)	*Pinus ponderosa* [1 year, 7 months]	Silty clay loam	1.02-1.28	19% increase, root dry weight
inger (1981)	*Pinus ponderosa*, *Pseudotsuga menziesii* [< 2 years]	Clay loam Sandy loam	0.88-1.10 1.06-1.35	Uneven root distribution Decrease in total root numbers Fine roots decrease No effect, root dry weight for *Pinus ponderosa* 66% reduction, dry root weight for *Pseudotsuga menziesii* on clay loam (no effect on sandy loam)
inore et al. 1969)	*Abies amabilis*, *Alnus rubra*, *Pinus contorta*, *Pseudotsuga menziesii*, *Thuja plicata*, *Picea sitchensis*, *Tsuga heterophylla* [2 years]	Sandy loam	1.32-1.45-1.59	44% reduction, root dry weight for *Thuja plicata*; no significant effect on other species

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[1] Estimates based on regression equation.

cultivated layer was sufficient for root growth; moreover, for two of three nursery blocks, nearly all fine roots were found in the upper soil layer. In addition, some evidence suggested that favorable moisture conditions after early sowing enabled seedling roots to penetrate the compacted subsoil. Recently, an unpublished report[5] showed conditions surprisingly similar to those observed by Minko. In a Northwest conifer nursery, a dense hard layer (bulk density ~ 1.6 g/cm^3) approximately 15 to 30 cm below the surface restricted root penetration of a grass cover crop; the condition was slightly more severe in dry than in moist soil.

Despite the lack of research thus far, the effects of increasing soil density are of special concern to the nursery manager. Compaction may be rare above the 15-cm depth because nursery soils are cultivated each year; however, below 15 cm compaction is relatively common, and is especially noticeable when drainage is impeded for long periods. The machinery used to manage the crop, the ability to control irrigation and fertilization, and the alternatives for tillage are all important aspects of nursery soil management affecting soil compaction.

PREVENTING AND AMELIORATING COMPACTED SOILS

Maintaining soil in good physical condition, loosening or tilling soil where compacted zones already exist, and controlling vehicular traffic to help avoid compaction must be part of an overall plan to maintain a good physical environment for tree growth in the nursery.

Maintaining Soil Physical Condition

Organic matter can aid soil resistance to compaction; it improves water retention and increases porosity and cation exchange capacity (see Blumenthal and Boyer 1982; review by Davey 1984). Verti-

Table 2.- Effect on shoots of young seedlings (< 2 years) as bulk density increased, over a variety of species and soil types, from selected laboratory studies.

Reference	Species [approximate age]	Soil type	Bulk density values	Effect on shoots as bulk density increased
			(*g/cm^3*)	
Heilman (1981)	*Pseudotsuga menziesii* [35 to 45 days]	Sandy loam, loam	1.38-1.57-1.76	No effect, total height
Tworkoski et al. (1983)	*Quercus alba* [40 days]	Silt loam	1.0-1.2-1.5	No effect, shoot height or dry weight
Sands and Bowen (1978)	*Pinus radiata* [150 days]	Sand	1.35-1.48	16% and 11% reduction, shoot dry weight and total height, respectively
			1.35-1.60	49% and 38% reduction, shoot dry weight and total height, respectively
Hatchell (1970)	*Pinus taeda* [150 days]	Loamy sand	1.26-1.46	42% reduction, shoot dry weight
		Loam	1.30-1.47	33% reduction, shoot dry weight
		Silt loam	1.34-1.62	56% reduction, shoot dry weight
		Sandy clay loam	1.14-1.28	56% reduction, shoot dry weight
		Clay loam	1.04-1.12	31% reduction, shoot dry weight
Trujillo (1976)	*Pinus ponderosa* [1 year, 7 months]	Silty clay loam	1.02-1.28	15% increase, shoot dry weight
Singer (1981)	*Pinus ponderosa*, *Pseudotsuga menziesii* [1 year, 10 months]	Clay loam	0.88-0.99-1.10	32% increase, shoot growth for *Pinus ponderosa*; no effect, *Pseudotsuga menziesii*
		Sandy loam	1.06-1.16-1.35	No effect, shoot growth
Minore et al. (1969)	*Abies amabilis*, *Alnus rubra*, *Picea sitchensis*, *Pinus contorta*, *Pseudotsuga menziesii*, *Thuja plicata*, *Tsuga heterophylla* [2 years]	Sandy loam	1.32-1.45-1.59	37% reduction, shoot dry weight for *Thuja plicata*; no effect, shoot dry weight for other species

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[5] David K. Maurer, 1983.

al mulching can improve root access to additional oisture and increase drainage through subsoiled lots (Gill 1971). Improving drainage to decrease ater content can minimize soil compaction (Warkenin 1984). Steinhardt and Trafford (1974) showed hat subsurface drainage of a wet clay reduced wheel inkage and lateral compaction from tractor traffic. otating crops also is instrumental in maintaing ood soil condition and has long been used to revent and ameliorate soil compaction (Larson and llmaras 1971).

Tilling Soil

The unfavorable soil conditions created by ompaction can often be improved if the soil is loosened. Tillage can improve soil aeration, infiltration, and pore space distribution and lower strength and bulk density. Generally, the beneficial effects of tillage are in the layer of soil disturbance. Voorhees et al. (1978) and Voorhees (1983), for example, showed that fall plowing was effective in ameliorating compaction from wheel traffic but that bulk density was reduced primarily in the plow layer. Compacted layers in the subsoil (plow pans) can be created by plowing to the same depth crop after crop; and the compaction zone below plow depth has been shown to persist for up to 9 years (Blake et al. 1976). However, not all compacted soils respond favorably to tillage. For example, nutrients may become deficient after deep plowing because topsoils generally contain more

Table 3.--Effect on tree height as bulk density increased in disturbed areas (skid trails, roads, logged), over a variety of species and soil types, from selected field studies.

Reference	Species [Age, years]	Soil type	Bulk density values [measurement depth]	Effect on tree height as bulk density increased	Disturbance type
			(g/cm³)		
Campbell et al. (1973)	*Pinus taeda* [1]	Clay loam	1.34-1.51 [surface 10 cm]	No effect, height growth	Skid trail
Hatchell et al. (1970)	*Pinus taeda* [1]	Sandy loam	0.75-0.92 [surface] 0.75-1.08 [surface]	21% reduction, total height 53% reduction, total height	Skid trail
Youngberg (1959)	*Pseudotsuga menziesii* [2]	Clay	0.88-0.95[1] [surface 15 cm] 0.88-1.55[1] [surface 15 cm]	22% reduction, height growth 42% reduction, height growth	Skid road, berm
Froehlich (1979b)	*Pseudotsuga menziesii* [4]	Sandy loam	0.87-0.95 [surface 15-23 cm] 0.87-0.99 [surface 15-23 cm]	11% reduction, height growth 21% reduction, height growth	Skid trail
	Pseudotsuga menziesii [5]	Clay loam	0.92-1.01 [surface 15-23 cm]	11% reduction, height growth	
Hatchell (1981)	*Pinus taeda* [5]	Silt loam	--	18% reduction, total height on compacted areas	Skid trail
Lockaby and Vidrine (1984)	*Pinus taeda* [5]	Loam	1.03-1.13 [surface 5 cm] 1.03-1.17 [surface 5 cm]	59% reduction, total height 39% reduction, total height	Primary skid road, deck
Wert and Thomas (1981)	*Pseudotsuga menziesii* [~ 14-18]	Loam	0.91-0.99 [5 cm] (1.09-1.26, 30 cm) 0.91-0.93 [5 cm] (1.09-1.13, 30 cm)	30% reduction, total height No difference, total height	Skid road
Froehlich (1979b)	*Pinus ponderosa* [17]	Sand	0.84-1.15 [surface 30 cm] 0.84-1.24 [surface 30 cm]	23% reduction, total height[2] 29% reduction, total height[2]	Skid trail
Froehlich (1979a)	*Pinus ponderosa* [~ 64]	Sandy clay loam	0.97-1.14 [7 cm] (1.03-1.12, 30 cm)	~ 6 to 12% reduction, growth rate	Usual logging, cattle use

[1] Bulk density values averaged over two plantations.

[2] Estimated effects based on regression equation.

available plant nutrients than subsoils (Burnett and Hauser 1967). In these cases, incorporating fertilizers with tillage (or soon thereafter) could help. Excessive traffic after tillage also should be avoided. Often, soil that is compacted, loosened, then compacted again will be denser after tillage (Cooper 1971). A tradeoff exists between compaction and tillage--although severe compaction can reduce growth, excessive loosening can be costly and can produce a poor environment for root growth (Gill 1971).

Several types of tools are used for tillage in agriculture (see Cooper 1971) and forestry (see Andrus and Froehlich 1983; Froehlich and McNabb 1983; Froehlich 1984). Investigating compacted conditions in skid trails, Andrus and Froehlich (1983) estimated that the portion of compacted soil effectively tilled by three conventional agricultural tools (brush blade, rock ripper, disk harrow) ranged from 20 to 45 percent; yet adding wings to the sides of ripping tines (via a prototype one-winged subsoiler) consistently tilled at least 80 percent of the compacted soil to a depth of ~ 45 cm. Regardless of the specific tool used, however, it is important to understand the soil conditions at the time of tillage and those created after loosening (Gill 1971). Subsoiling,[6] for example, must be performed under relatively dry conditions so that the implement fractures the compacted zone. When soil is too moist, the implement can pass through the dense soil layer with little amelioration. Furthermore, the restorative action must be dictated by soil conditions, not by a standard operation (e.g., using a tool at a fixed setting).

Tillage experiments have shown a wide range of results. Gill (1971) and Burnett and Hauser (1967) cite numerous studies where tillage has improved either root development or crop yield. Yet in some cases, tillage may bring about the desired soil physical changes without altering yield. Water seems critical in determining crop response. When water is not limiting, yields after tillage may not be increased; but where water movement and root development are restricted by compaction, deep plowing has increased crop yields most (Burnett and Hauser 1967). Burnett and Hauser (1967) concluded the primary benefits of deep tillage to be increases in stored water (due to either improved infiltration or change in particle arrangement) or in root proliferation (enabling roots to obtain water). Additionally, they find that the soil physical changes created by tillage are long term if soils are fine textured, the tillage operation is drastic (e.g., large plows), and compacted zones are essentially genetic, but are more short term if soils are medium to coarse textured, the tillage implement is a subsoiler or chisel, and compacted layers are induced by machinery.

The literature on tillage effects on forest species or soils is not as voluminous as that for crop species. Tilling previously compacted forest soils has generally been beneficial (Andrus and Froehlich 1983); over a range of soil and tillage types, increases of 11 to 83 percent in seedling survival and 13 to 73 percent in seedling height growth have been reported. Nursery seedling height of *Pinus radiata* seedlings grown in ripped areas was 60 percent greater than that in unripped areas (Minko 1975). Yet Hatchell (1970) found that loose ing treatments of compacted soil cores from a rang of soil types did not significantly increase eithe root or shoot dry weight of *Pinus taeda* seedlings after one growing season, and Warkentin (1984) warned that despite the benefits claimed by nurser managers, the effects of ripping may be only temporary.

Managing Traffic

Intensive management requires the judicious use of machinery to minimize compaction. The following recommendations are from Lull (1959), Gill (1971), Greacen and Sands (1980), Adams and Froehlich (1981), and Warkentin (1984):

Timing operations: If possible, conduct operations on drier soils. Using moisture-based restrictions (especially those based on laboratory tests with unrealistically large forces applied), although sound in theory, is often not practical nor accurate in the field. In addition delays in field operations due to wet soils increase production costs. Texturally well-grade soils which are low in organic matter may be mor susceptible to compaction, so particular care must be taken when traffic is necessary on these sites. Most soils, however, are susceptible to compaction unless already compacted.

Choosing machinery: Modified equipment design (e.g., long-boom sprayers) or use of low-ground-pressure equipment may help minimize the forces applied to soil during operations. Gill (1971) stated that the rear wheel of the agricultural tractor was the worst soil-compacting device use in a crop production system. However, the versatility of the rubber tire probably justifies its use, especially on firm ground. When soils are wet, traction devices such as low-pressure tires may provide an alternative. If load and weight are equal, crawler tractors compact the soil les than wheeled tractors, and surface pressures are reduced further if wider tracks are used. Howeve a larger area is subject to mechanical vibration with crawler tractors; therefore, estimates comparing ground pressure between crawler and tire tractors may not indicate the entire compactive effect. The use of fixed paths in the nursery also helps prevent compaction in the crop area.

CONCLUSION

Compaction can detrimentally affect soil physical characteristics, resulting in poor tree growth. Yet no one knows whether compaction in forest nurseries is severely inhibiting growth of tree seedlings. However, because of the intensive use of the land required by cultural manipulation of soil and crop, the potential for compaction is concern shared by most nursery managers. Maintenance of good soil physical conditions, proper tillage, and sound management of vehicle traffic are all important parts of a system to prevent and help ameliorate compacted soils.

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[6] "Subsoiling" and "ripping" often refer to the same type of tillage treatment, but subsoiling usually is deeper.

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LITERATURE CITED

Adams, P.W. 1983. Recognizing and measuring soil compaction. In Workshop: Forest soil compaction: problems and alternatives. [LaGrande, Oreg., March 22-23, 1983] Department of Forest Engineering, Oregon State University, Corvallis.

Adams, P.W., and H.A. Froehlich. 1981. Compaction of forest soils. Oregon State University Extension Service PNW 217, 13 p. Oregon State University, Corvallis.

Andrus, C.W., and H.A. Froehlich. 1983. An evaluation of four implements used to till compacted forest soils in the Pacific Northwest. Forest Research Laboratory Research Bulletin 45, 12 p. Oregon State University, Corvallis.

Blake, G.R. 1965. Bulk density. p. 374-390. In Methods of soil analysis [C.A. Black, ed.]. American Society of Agronomy, Madison, Wis.

Blake, G.R., W.W. Nelson, and R.R. Allmaras. 1976. Persistence of subsoil compaction in a mollisol. Soil Science Society of America Journal 40:943-948.

Blumenthal, S.G., and D.E. Boyer. 1982. Organic amendments in forest nursery management in the Pacific Northwest. USDA Forest Service Administrative Report, 73 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Bodman, G.B., and G.K. Constantin. 1965. Influence of particle size distribution in soil compaction. Hilgardia 36:567-591.

Burnett, E., and V.L. Hauser. 1967. Deep tillage and soil-plant-water relationships. p. 49-52. In Proceedings: Tillage for greater crop production. American Society of Agricultural Engineers, St. Joseph, Mich.

Campbell, R.G., J.R. Willis, and J.T. May. 1973. Soil disturbance by logging with rubber-tired skidders. Journal of Soil and Water Conservation 28(5):218-220.

Cooper, A.W. 1971. Effects of tillage on soil compaction. p. 317-364. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Davey, C.B. 1984. Nursery soil organic matter: management and importance. p. 81-86. In Forest nursery manual: production of bareroot seedlings [M.L. Duryea and T.D. Landis, eds.]. Martinus Nijhoff/Dr W. Junk Publishers, The Hague/Boston/Lancaster for Forest Research Laboratory, Oregon State University, Corvallis.

Day, R.J. 1984. Water management. p. 93-105. In Forest nursery manual: production of bareroot seedlings [M.L. Duryea and T.D. Landis, eds.]. Martinus Nijhoff/Dr W. Junk Publishers, The Hague/Boston/Lancaster for Forest Research Laboratory, Oregon State University, Corvallis.

Duffy, P.D., and D.C. McClurkin. 1974. Difficult eroded planting sites in north Mississippi evaluated by discriminant analysis. Soil Science Society of America Proceedings 38:676-678.

Eavis, B.W. 1972. Soil physical conditions affecting seedling root growth I. Mechanical impedance, aeration and moisture availability as influenced by bulk density and moisture levels in a sandy loam soil. Plant and Soil 36:613-622.

Flint, A., and S. Childs. 1984. Development and calibration of an irregular hole bulk density sampler. Soil Science Society of America Journal 48:374-378.

Foil, R.R., and C.W. Ralston. 1967. The establishment and growth of loblolly pine seedlings on compacted soils. Soil Science Society of America Proceedings 31:565-568.

Forristall, F.F., and S.P. Gessel. 1955. Soil properties related to forest cover type and productivity on the Lee Forest, Snohomish County, Washington. Soil Science Society of America Proceedings 19:384-389.

Freitag, D.R. 1971. Methods of measuring soil compaction. p. 47-103. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Froehlich, H.A. 1973. The impact of even-age forest management on physical properties of soils. p. 190-220. In Proceedings: Even-age management symposium [R.K. Hermann and D.P. Lavender, eds.]. [Corvallis, Oreg., August 1, 1972] Oregon State University, Corvallis.

Froehlich, H.A. 1974. Soil compaction: implication for young-growth management. p. 49-64. In Proceedings: Managing young forests in the Douglas-fir region [A. Berg, ed.]. [Corvallis, Oreg., June 14-16, 1972] Oregon State University, Corvallis.

Froehlich, H.A. 1979a. Soil compaction from logging equipment: effects on growth of young ponderosa pine. Journal of Soil and Water Conservation 34(6):276-278.

Froehlich, H.A. 1979b. The effect of soil compaction by logging on forest productivity. Final report to the U.S. Bureau of Land Management for contract 53500-CT4-5(N), 19 p. School of Forestry, Oregon State University, Corvallis.

Froehlich, H.A. 1984. Mechanical amelioration of adverse physical soil conditions in forestry. p. 507-521. In Proceedings: Symposium on site and productivity of fast growing plantations [D.C. Grey, A.P.G. Schonau, and C.J. Schultz, eds.]. [April 30 to May 11, 1984] IUFRO, Pretoria and Pietermaritzburg, South Africa.

Froehlich, H.A., and D.H. McNabb. 1983. Minimizing soil compaction in Pacific Northwest forests. p. 159-192. In Forest soils and treatment impacts. Proceedings: Sixth North American Forest Soils Conference. [Knoxville, Tenn., June 1983] University of Tennessee, Knoxville.

Gifford, G.F., R.H. Faust, and G.B. Coltharp. 1977. Measuring soil compaction on rangeland. Journal of Range Management 30:457-460.

Gill, W.R. 1971. Economic assessment of soil compaction. p. 431-458. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Gooderham, P.T., and N.M. Fisher. 1975. Experiments to determine the effect of induced soil compaction on soil physical conditions, seedling root growth, and crop yield. Ministry of Agriculture, Fisheries and Food, Technical Bulletin 29:469-480. Wye College, University of London.

Grable, A.R. 1971. Effects of compaction on contact and transmission of air in soils. p. 154-164. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Greacen, E.L., and R. Sands. 1980. Compaction of forest soils, a review. Australian Journal of Soil Research 18:163-189.

Halverson, H.G., and R.P. Zisa. 1982. Measuring the response of conifer seedlings to soil compaction stress. USDA Forest Service Research Paper NE-509, 6 p. Northeastern Forest Experiment Station, Broomall, Pa.

Harris, W.L. 1971. The soil compaction process. p. 10-44. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Hatchell, G.E. 1970. Soil compaction and loosening treatments affect loblolly pine growth in pots. USDA Forest Service Research Paper SE-72, 9 p. Southeastern Forest Experiment Station, Asheville, N.C.

Hatchell, G.E. 1981. Site preparation and fertilizer increase pine growth on soils compacted in logging. Southern Journal of Applied Forestry 5(2):79-83.

Hatchell, G.E., C.W. Ralston, and R.R. Foil. 1970. Soil disturbances in logging. Journal of Forestry 68:772-775.

Heilman, P. 1981. Root penetration of Douglas-fir seedlings into compacted soil. Forest Science 27(4):660-666.

Hildebrand, E.E. 1983. Influence of soil compaction on soil functions on forest sites (Inhibitory effect on beech regeneration). Der einfluss der bodenverdichtung auf die bodenfunktionen im forstlichen standort. Forstwissenschaftliches Centralblatt 102(2):111-125.

Howard, R.F., and M.J. Singer. 1981. Measuring forest soil bulk density using irregular hole, paraffin clod, and air permeability. Forest Science 27(2):316-322.

Kemper, W.D., B.A. Stewart, and L.K. Porter. 1971. Effects of compaction on soil nutrient status. p. 178-189. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Larson, W.E., and R.R. Allmaras. 1971. Management factors and natural forces as related to compaction. p. 367-427. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Lockaby, B.G., and C.G. Vidrine. 1984. Effect of logging equipment traffic on soil density and growth and survival of young loblolly pine. Southern Journal of Applied Forestry 8(2):109-112.

Lowerts, G.A., and J.M. Stone. 1982. The effect of soil bulk density on nursery sweetgum seedling growth. Tree Planters' Notes 33(3):3-5.

Lull, H.W. 1959. Soil compaction on forest and range lands. USDA Forest Service Miscellaneous Publication 768, 33 p. Washington, DC.

McKibben, E.G. 1971. Introduction. p. 3-6. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

McNabb, D. 1981. Compaction of southwest Oregon soils--shear strength. Oregon State University Extension Service Forestry Intensified Researc Report 3(1):3-4. Oregon State University, Corvallis.

Minko, G. 1975. Effects of soil physical properties, irrigation, and fertilization on Pinus radiata seedling development in the Benalla nursery. Forests Commission Victoria Forest Technical Papers 22:19-24.

Minore, D., C.E. Smith, and R.F. Woollard. 1969. Effects of high soil density on seedling root growth of seven northwestern tree species. USD Forest Service Research Note PNW-112, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Pearse, P.H. 1958. A study of the effects of soil compaction on the early development of seedlings of Douglas-fir and western hemlock. University of British Columbia Forest Club Research Note 16, 7 p. Vancouver.

Perry, T.O. 1964. Soil compaction and loblolly pin growth. Tree Planters' Notes 67:9.

Power, W.E. 1974. Effects and observations of soil compaction in the Salem District. USDI-BLM Technical Note 256, 12 p. Salem, Oreg.

Rosenberg, N.J. 1964. Responses of plants to the physical effects of soil compaction. Advances in Agronomy 16:181-196.

Sands, R., and G.D. Bowen. 1978. Compaction of sandy soils in radiata pine forests. II. Effec of compaction on root configuration and growth of radiata pine seedlings. Australian Forest Research 8:163-170.

Sands, R., E.L. Greacen, and C.J. Gerard. 1979. Compaction of sandy soils in radiata pine forests. I. A penetrometer study. Australian Jour nal of Soil Research 17:101-113.

Sidle, R.C. 1980. Impacts of forest practices on surface erosion. Oregon State University Exter sion Service PNW 195, 15 p. Oregon State Unive sity, Corvallis.

Sidle, R.C., and D.M. Drlica. 1981. Soil compacti from logging with a low-ground pressure skidd in the Oregon Coast ranges. Soil Science Society of America Journal 45:1219-1224.

Singer, M.J. 1981. Soil compaction-seedling growt study. Final technical report to the United

States Forest Service Region 5 for cooperative agreement USDA-7USC-2201 supplement 43, 51 p.

einbrenner, E.C. 1955. The effect of repeated tractor trips on the physical properties of forest soils. Northwest Science 29:155-159.

teinbrenner, E.C., and S.P. Gessel. 1955a. Effect of tractor logging on soils and regeneration in the Douglas-fir region of southwestern Washington. Society of American Foresters Proceedings 19:77-80.

teinbrenner, E.C., and S.P. Gessel. 1955b. The effect of tractor logging on the physical properties of some forest soils in southwestern Washington. Soil Science Society of America Proceedings 19:372-376.

teinhardt, R., and B.D. Trafford. 1974. Some effects of sub-surface drainage and ploughing on the structure and compactability of a clay soil. Journal of Soil Science 25:138-152.

rouse, A.C. 1971. Soil conditions as they affect plant establishment, root development, and yield. Present knowledge and need for research. p. 225-240. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

rujillo, D.P. 1976. Container-grown ponderosa pine seedlings respond to fertilization. USDA Forest Service Research Note RM-319, 3 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

workoski, T.J., J.A. Burger, and D.W. Smith. 1983. Soil texture and bulk density affect early growth of white oak seedlings. Tree Planters' Notes 34(2):22-25.

oorhees, W.B. 1983. Relative effectiveness of tillage and natural forces in alleviating wheel-induced soil compaction. Soil Science Society of America Journal 47:129-133.

Voorhees, W.B., C.G. Senst, and W.W. Nelson. 1978. Compaction and soil structure modification by wheel traffic in the northern Corn Belt. Soil Science Society of America Journal 42:341-349.

Warkentin, B.P. 1971. Effects of compaction on content and transmission of water in soils. p. 126-153. In Compaction of agricultural soils [K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg, eds.]. American Society of Agricultural Engineers, St. Joseph, Mich.

Warkentin, B.P. 1984. Physical properties of forest-nursery soils: relation to seedling growth. p. 53-61. In Forest nursery manual: production of bareroot seedlings [M.L. Duryea and T.D. Landis, eds.]. Martinus Nijhoff/Dr W. Junk Publishers, The Hague/Boston/Lancaster, for Forest Research Laboratory, Oregon State University, Corvallis.

Warnaars, B.C., and B.W. Eavis. 1972. Soil physical conditions affecting seedling root growth. II. Mechanical impedance, aeration and moisture availability as influenced by grain-size distribution and moisture content in silica sands. Plant and Soil 36:623-634.

Wert, S., and B.R. Thomas. 1981. Effects of skid roads on diameter, height, and volume growth in Douglas-fir. Soil Science Society of America Journal 45:629-632.

Youngberg, C.T. 1959. The influence of soil conditions, following tractor logging, on the growth of planted Douglas-fir seedlings. Soil Science Society of America Proceedings 23:76-78.

Zisa, R.P., H.G. Halverson, and B.B. Stout. 1980. Establishment and early growth of conifers on compact soils in urban areas. USDA Forest Service Research Paper NE-451, 8 p. Northeastern Forest Experiment Station, Broomall, Pa.

Computer Use in Nursery Management[1]

Jerry Grebasch[2]

Nursery Management is a blend of art and science. The science aspects give us information that is measureable and recordable. This is the area inwhich the computer offers its value. Nursery Managers need not be computer programers, but need to be able to interact with programers. The Iowa State Forest Nursery uses six basic programs that store and retrieve information on seed lots, seedbed inventory, soil status, tree ordering, cultural practices and cost analysis.

For the past 21 years I have managed the State Forest Nursery for the Iowa Conservation Commission. Currently, production is 6 million seedlings. This is divided between conifers, hardwoods, and shrub material. Average order size is slightly over 1,200 seedlings, with between 4,500 to 5,000 orders being processed annually.

We grow trees so that we can meet reforestation needs. In many states, this can vary from large block plantings to states where plantings are relatively small and always mixed with an eye to wildlife habitat. In all cases, the seedlings must grow. There are some nurserymen who feel that their job ends when the seedlings go out the front gate. But many of us understand that we must follow these seedlings into the field and insure that the plantings are successful. We deal with a great number of variables to achieve that goal. The success of the nursery operation depends on the fact that the plants must survive and grow in the field.

I believe that nursery management is both an art and a science. In many instances, both areas affect our management procedures. As an art, we look through nursery beds, touch seedlings, pull seedlings up to look at the roots, feel the soil with our hands to check the moisture content, look with our eyes in terms of the quality and overall condition, and sometimes work from the heart on how we feel our stock is doing. As a science, nursery management requires keeping records and trying to duplicate results over successive periods of time. It's this aspect of the nursery that I'd like to address myself today, the science of record keeping and the use of computers for this monumental task.

The variation of years of experience among this group points to the need for records. Those who have been managing for a long period of time have gained a wealth of knowledge but it is essential that this knowledge be passed on to our successors, so that they too can continue to produce high quality stock. Records and notes can be passed on. I remember when I first started in this business, my teacher and I would go into the field. Various characteristics were brought to my attention for example, picking up a handful of soil to feel the moisture content. At the time, it was difficult for me to sense. Only time and experience helped. We'd go into the cold storage facility, and I'd be asked to feel the condition of the roots. Quite frankly, it was again most difficult for me to experience the same feelings that my teacher experienced. However, when we were able to get into the office and I could look at the records, I could see what the watering schedule was and then go back to the field to look at the condition of the stock. I was better able to begin understanding nursery management.

Tom Landis has asked me to address the question of when to buy a computer? My answer to tha is as soon as you possibly can. I know that some are further ahead in programs for record keeping but it's none too soon for all to start recording information. I haven't found a better method of record keeping than the computer. Before the computer, many times I found myself sacrificing the information just because it would take too long to write it down. I remember walking into a nursery office and having the manager show me on the wall a board which displayed all the cultural practice that were performed on the various nursery beds. What was shown was the desired rate of fertilization and other cultural practices. When I asked what was actually applied, there was no answer. In keeping records the desired as well as the actual results need to be recorded. The computer allows greater flexibility in which to achieve those results. Then when playing Sherlock Holmes we can refer back to what was actually applied and egin to analyze the reasons for the possible sucess or failure of that crop. A quick survey sugests that many have written or are in the process f writing their own software programs. The major oncern that I have for this entire computer proiferation is that we are repeating what others ave done in the past. I think that it is esential that we stop re-inventing the wheel.

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[1] Paper presented at the Intermountain Nurseryman's Association Meeting, Fort Collins, CO, Aug. 13-15, 1985.

[2] Jerry Grebasch is Nursery Manager for the Iowa State Forest Nursery in Ames, Iowa.

For those areas where programs haven't been ritten, I'd like to discuss some of the possible roblems. This comes mainly from the heart, along ith much experience. I think the first thing ou must do is analyze the person who will be dong the programming. If that person is well rounded in forestry and nursery management you re ahead of the game. If not, as was my expeience, you are going to spend alot of time and nergy explaining to them what the nursery process s and getting them to understand your needs. One echnique I have found quite effective is to litrally draw a picture of the end result. Remember, he programs and software are not going to make ecisions for you but rather aid you in making deisions; therefore, the data that you are looking t must be in usable form. It must flow and work ell with your operations. Secondly, communicaions is a very important aspect of software deelopment. I spent the first six months working ith the programmer just to develop the terminolgy. One of the greatest frustrations this prorammer had were the exceptions that I was willing o tolerate. The human mind is able to assimilate nd put into a meaningful form diverse data on hich to base decisions. To the contrary, the omputer has to deal with each bit of information o that if you're going to have exceptions, they ave to be worked into the programming. Of course, xceptions then make the programming job much more ifficult.

I believe you must have an understanding of ccounting. There's nothing worse than presentng information to the comptroller and not using asic accounting principles. They will dismiss our information so that your work and good inentions go down the drain.

One of the more important aspects of proviing information is to present it in logical form. t is important to think through the steps from mputting the data to the final report. These ogical steps are necessary in the programming nd will prevent headaches in the future. As we ere developing one of our programs, things were oing very well until I asked if a particular bit f information could be added. The expression on he programmer's face said just the opposite as he aid "Yes, certainly we can do just about anything, ut we're going to have to go back to square one, ecause there is not space left in that field to ecord the data." Forethought in determining your oals will prevent or at least reduce some of the roblems.

It is important to have a good working relaionship with the people writing the program. Be ure to ask for the cost estimate of the program in general, and specifically for any changes you request. At one point, I requested that $50 of wages be transferred to another area. It was sometime later I learned that the charge for that correction was $300! Since then, I always ask about the difficulty of the correction and the estimated cost.

There are several things that I would do differently. The first item would be to become more knowledgeable about computers and understand the limitations. I do not want to become a computer programmer, but I do want to know what the computer is capable of and then be able to use that information to make management decisions. I certainly feel that we need to develop educational programs that would enable managers to understand the computer. Many times, in seminars or short courses, we are told how to write programs. I don't think that's necessarily what we need. As I mentioned earlier, think out the problem. Don't rush into having something designed without thinking it through very carefully, no matter who is doing the writing. A brief description or flow chart will aid you in the whole process of program development.

There's an area that I'm still very interested in, but because of finances, have been unable to move into it thus far. The nursery is accumulating a great deal of data on growing stock, but there is one more step that needs to be implemented, the use of bar coding. Bar coding our seedling bags would allow us to trace nursery cultural practices back to the individual order. Then we would be able to develop a data base that would allow us to investigate our nursery product after it has left the nursery.

At the present time, the State Forest Nursery has six basic computer programs. First, is our seed lot information. Second, is the nursery bed inventory. Third, nursery soil data. Fourth, tree order system. Fifth, cultural practices records, and sixth, a cost analysis system.

I'd like to first address myself to the seed lot information. This is a small program but very important in two respects. First, to have at your fingertips the seed lot information that you feel important; and secondly, to have a value of your seed inventory. I was interested in some basic information: the species name, seed lot code, moisture content, germination percent, purity percent, seeds per pound, date that it was tested, who tested it, the source purchased from, the seed origin, crop year, elevation, cost per pound, the beginning weight, current weight, and the dollar value of the seed. This program was one I had written myself. I used Datastar as the input format so it provides me with a fill-in-the-blanks screen. Output is generated through Reportstar. I use this primarily for seeding information in order to know what seed we have available, the quantity, germination percent, seeds per pound, location collected, and so forth so that I can then determine which seed lot to use for our current seeding. The next report is used for our cost accounting people to show current seed on hand and the value of that seed.

The second computer program is our nursery bed inventory. This was a program originally developed by Dr. Ware at Iowa State University, and then modified by Dan Garst to be used on the IBM PC. I do not intend to go into detail on the statistical analysis of this program but rather address how the data is entered into the computer. If any of you are interested in a copy of the thesis, please contact me. As the sample plots are taken, data is collected on sheets right in the field. These sheets are then brought into the office and using a line editor similar to MS DOS Edlin, entered into the computer. The first program is for checking errors. As an example, if you are using total number of seedlings in a plot as well as saleable number of seedlings, had those numbers been accidentally transposed, the information would be flagged and you would be able to go back and correct the data. Other items being checked are consistency of data and the reasonableness of the numbers. If the data stands up, it is then run through the second program. I should have stated earlier that our initial sample is 20 plots per species and age class. The program is run on the basic 20 plots to determine if an additional number of samples is necessary to achieve the desired degree of accuracy. This program will indicate the additional number of plots necessary and the spacing interval. With the additional plots taken and the data recorded, we then are able to run our final report to yield the number of plantable seedlings and the standard error. This is then the basis for our nursery sales.

The third computer program is soil analysis data. We have purchased a Hach Soil Testing System which works very effectively for us. Data is obtained annually on the three major nutrients and seven micro-nutrients, from samples of all sections of the nursery. Of course, if there are any signs of problems, we will take soil samples immediately. The data is then recorded on paper so that it can be entered into the computer. Current data is merged with previous information to provide an historical basis in chronological order. If there is a need, we can provide a printout for the entire nursery or for a particular location in the nursery.

Fourth is the tree order system that currently handles between 4,500 and 5,000 orders, with an undefined capacity. The beginning document is the application that the landowner submits. The data is entered into our computer using a fill-in-the-blanks system which makes data entry easy for the operator. Items that are recorded include: landowner and address, shipping address if it's different from the landowner's location, county where the trees are to be planted, whether it is to be shipped or picked up, and whether sales tax is to be paid. Each species that the landowner is ordering is recorded by code. Also displayed on the screen is current inventory for that species which is then reduced by the amount of that order. On the right hand of the screen, the current billing cost of trees and tax is applicable is shown. A major decision that we made in establishing thi program was to allow changes to the order until just prior to shipping. I know that many will disagree, but we felt in order to better serve th public, we wanted to be sensitive to their needs. If a change is to be made, a correction sheet to the order is completed and the information is entered into the computer. The system is interactive so we are able to go into the data base an change whatever the landowner wishes. An invoic can be generated at any time after the order is entered. The invoice includes order number, species requested and available, cost, and due date. The invoice is generated with a due date so that payment not received in time will cancel the order and return the stock to our sales inventory.

A cumulative, alphabetized listing of customers is generated to enable quick cross referencing of the tree order number when a custome calls.

Once the invoice has been mailed and paymen received, a credit change program is used to recor order number, date of payment, and the amount paid At the end of each entry session, a printout is generated to indicate the financial transactions of that session. Because of the last minute change capability, a second or third invoice can be issued if necessary. Any over payment reflects th need for a refund.

As shipping time approaches, a bagging list prepared. The bagging list can be composed of a orders to be shipped, a group of orders to be shipped, a group of orders to be picked up, or a combination of orders. The bagging list is used internally in our shipping office as a means of checking the day's work and identifying the speci composition of each order.

The second item generated is a bag label. Th is a gummed label that is applied to our shippin bag. It carries the order number, the name and address, and the number of seedlings in each bag This aids the people who are preparing the order The combinations and maximum amount that can fit into a bag change as variations occur in the sto Corrections can easily be made to the program th generates the labels.

Another item is a report sent to the distri forester indicating the landowner, county to be planted, and the make up of the order. This repo can be issued throughout the season to inform di trict foresters of orders received and processe by the nursery. This is helpful in improving co muncations between the nursery and the field.

The end of the season sales report shows amo of stock sold, amount shipped, and amount picke There is a variety of other information all pertaining to the orders.

The fifth and sixth computer programs are a mbination of cultural practices and cost analysis. ey are grouped together because as data is colcted on the cultural practices, you can very easily sign the costs to those activities. We have a bor time classification system that is broken down to four areas. The 100 series are miscellaneous tivities such as miscellaneous weeding, spraying, d fertilizing. The 200 series are labor that is rectly applicable to a species and age class. e 300 series represents what we call cooperation th others in the Conservation Commission, Iowa ate University, and the U. S. Forest Service. e 400 series is the seed collection program. We e able to indicate the number of hours spent colcting specific species of seed.

A general classification meets the necessity identifying and coding a wide variety of supies and equipment on the nursery. The first part a code classification for all seeds, fertilizers, ipping bags, etc. Each piece of equipment valued excess of $2,000 has a series of code numbers signed to record labor, fuel, mileage, oil, deeciation, parts, and service.

Lastly, there is a series of miscellaneous codes r work that is done in the nursery: garbage llection, natural gas bills, and so forth. All these costs are coded when being entered.

The nursery has three sources of input data. e time report, titled Weekly Activity Report, is mpleted by each employee based on half-hour inements. Second input source is the claims for rchases by the nursery. The claim is coded incating the piece of equipment or general category at it should be charged to. Third input data is terials and amount used, desired rate, and location of area where applied, which are all rerded on paper by the employee doing the work d then entered into the computer once a week. ere is a checking program that data can be run ainst to detect obvious errors. Once all the data is recorded and run through the checking program stream files are permanently updated. The following is a sample of the wide variety of reports which can be derived from this data base. The bed assignment report contains location, age class, species, bedding area, bed and path area, and seed lot code. This report can also be rearranged by species. These reports are very effective for identifying useable beds for fall seeding. The next report is a current inventory of supplies on hand, including the quantity on hand, the date last purchased, quantity last purchased, and the unit price. The equipment report indicates the fuel cost per hour, gallons per hour, labor and depreciation as well as the total operating costs. These reports are invaluable when considering replacements.

There is a report on each employee which gives a break down of hours and dollars spent in each time classification. Thus, one can easily see where employees are being utilized.

The report summarizing the cost of growing seedlings shows both the direct and indirect costs. These reports can be combined to give costs of producing individual species or groups such as conifers, hardwoods, or shrubs, or total figures for the entire nursery.

Cultural practices report shows in chronological order all of the cultural practices such as the time of fertilization, time and amount of spraying, as well as the desired and actual rates of application. This then is an important tool for developing a complete program for growing nursery stock.

There is no doubt that a computer can be a very valuable tool for nursery managers. With careful planning and attention to detail, records can be developed to insure repeated production of high quality stock.

Recent Developments in the Management of Nursery Pests[1]

Whitney S. Cranshaw[2]

Abstract. Insect pest complexes in the intermountain region continue to change rapidly as new pest species are introduced and different plants become favored in landscapes. Among the more serious of the new pest species to become colonized, has been the honeysuckle witches broom aphid which now threatens the future of tartarian types of honeysuckle throughout most of the country. Developments in insect management, however, continue to keep pace with these changing needs. Use of sex pheromone based insect trapping has expanded so that it is now routinely used to monitor flights and associated egg laying periods for several difficult insect control problems. Insecticide technology has also advanced, with greatest current development among synthetic pyrethroids. Also, broader spectrum Bacillus thuringiensis preparations and soap/detergent sprays are offering less hazardous insect control options that are particularly desirable for high population areas. Finally, expanded use of soil applied systemic insecticides has good promise for control of many insect and mite problems. Advantages of these latter treatments are elimination of drift problems, relative ease of application, and generally thorough plant coverage. Limitations include the need for adequate watering, high toxicity, and the potential for direct effects on plant growth.

Several dozen insect and mite species seriously damage woody plants in the intermountain region. Most threatening are the various bark beetles, (Dendroctonus, Ips, Scolytus, etc.), many of which introduce pathogenic fungi into living trees. Borers, primarily clearwing borers, (Sessiidae), are serious pests of certain trees and shrubs and are capable of directly attacking and killing healthy plants. Many other pest species more indirectly affect the overall vigor and health of woody plants. These include insects and mites which suck plant sap (aphids, scale insects, spider mites) and the numerous beetles, caterpillars, and sawflies which are capable of defoliating plants. Among these latter pest species are several which commonly cause serious aesthetic damage to woody plants (e.g. elm leaf beetle, douglas fir tussock moth, pear slug, etc.)

Unfortunately, the status of woody plant pests in the region is not static and many situations have lately changed for the worse. This, in part, is due to changes in plant species used in urban landscaping. For example, honeylocust has been very extensively planted in recent years and this "pest-free" species is developing numerous serious disease, insect, and mite problems.

Also important has been the widespread introduction of new plant pests into the region. This trend has undoubtedly accelerated in recent years with the population influx. Species lists current a decade ago now have to be updated as many "Eastern" species have become established. For example, during 1985 the gypsy moth, viburnum borer (Synanthedon viburni), and a new species of sawfly infesting juniper were first recorded as established along parts of Front Range Colorado.

Also important has been the spread and establishment of "exotic" species. The most important of these recent arrivals to the nursery industry is the honeysuckle witches broom aphid. This aphid seriously threatens the future of tartarian varieties of honeysuckle in the United States. At present, the honeysuckle witches broom aphid heavily damages this commonly planted shrub throughout the mid-West (including Colorado) and its spread into Utah was confirmed in 1985. Management of this insect is discussed in the C.S.U. Service-in-Action Sheet 5.546 (Cranshaw 1985b).

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[1] Paper presented at the Intermountain Nurseryman's Association Meeting, Fort Collins, Colorado, August 13-15, 1985.

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Improvements in insect management have also progressed in many areas to meet these new challenges.

The use of insect sex pheromone traps in insect pest management has expanded greatly in the past decade. In the past, use of these traps has been greatest in detecting the presence of new pest species in an area. For example, gypsy moth movements continue to be monitored with these traps in many areas of the country.

The most useful application of pheromone technology for plant health care professionals is to follow flights of key insects. This can greatly improve the timing of insecticide applications for plant protection, since flights are correlated with egg laying periods. Among the many pheromone traps available at present, those used for tracking clearwing borers (lilac/ash borer, peach tree borer, viburnum borer), leafrolling caterpillars, and certain pine tip moths are most commonly in use in woody plant protection.

Use of pheromones directly for insect control has also been attempted experimentally. Primary strategies involve either mass trap outs (e.g., certain bark beetles) or mating confusion applications. At present, practical uses of these techniques in nursery production have not been demonstrated.

New developments in insecticides have also occurred, although the pace appears to have slowed in recent years. Primary areas of development involve synthetic pyrethroid insecticides, microbial insecticides, and insect growth regulators.

Development is strongest among the synthetic pyrethroid products. Synthetic pyrethroids are chemically derived from the naturally-occurring pyrethrins which are found as fast-acting insecticides in many household aerosol sprays. The synthetic pyrethroids are marked by having extremely high activity, being effective at rates 1/10 - 1/100 of currently used materials. Mammalian toxicity of the synthetic pyrethroids is generally low, particularly when diluted at use rates, although some individuals report irritation by these materials. Most synthetic pyrethroids have a broad spectrum of activity and a few are also effective miticides. Fluvalinate (Mavrik) is the most recent of these materials to get labelling on woody plants, but many other synthetic pyrethroids should be marketed in the next few years.

Microbial insecticide development primarily concerns improvement of Bacillus thuringiensis products. This area has drawn considerable interest among many biotechnology companies. B. thuringiensis products with effectiveness against leaf-feeding beetles (as well as caterpillars) are being tested successfully. The exceptional safety of B. thuringiensis recommends it for use in high population areas.

Highly promising, but still experimental, is the use of insect parasitic nematodes against soil insects. Several nematode species have demonstrated effectiveness for control of black vine weevil larvae. In 1985, C.S.U. trials also conducted nematode applications which demonstrated control of raspberry crown borer and white grubs.

Rediscovery of an "old" insecticide, soaps, and use of detergents is also becoming more widespread. These materials have often proved very effective for controlling many small insects (aphids, psyllids, etc.) and mites. Safety to the user of soaps and detergents is a major factor in their increased use. Although initial control may be less than with standard insecticides, soap/detergent applications often spare many beneficial insect predators and parasites allowing longer term control. The use of these materials is discussed in C.S.U. Service-in-Action Sheet 5.547, Use of Soaps and Detergents for Insect Control in Colorado (Cranshaw 1985a).

Insecticides with systemic activity (i.e., are translocated within the plant) are also an available tool in insect management on woody plants. These insecticides are often particularly useful for control of "hard-to-reach" insects such as aphids. Greatest use has involved systemic insecticides formulated for use as foliar sprays. These include acephate (Orthene), dimethoate (Cygon), and oxydimetonurethyl (Metasystox-R).

Many of these materials, and others, can be used as soil applications. This treatment method has several major advantages which include: elimination of insecticide drift, generally thorough plant coverage, and ease of application. Soil applied systemic insecticides are routinely used for production of many greenhouse and vegetable crops but are underutilized with woody plants.

Trials conducted at C.S.U. during 1984-85 with soil applied systemic insecticides have targeted 3 difficult-to-control insect problems - honeysuckle witches broom aphid, honeylocust pod gall midge, and the pinyon "pitch mass borer" (Dioryctria sp.). Results have been variable and demonstrate the utility and limitations of these soil applications.

Honeysuckle witches broom aphid control has been outstanding with use of Metasystox-R and Cygon applied as soil drenches. Rates of these materials at 1/16 tsp./3 gallon nursery can have given complete control of this insect for over one month. These results are consistent with those achieved by some Denver area tree care professionals in 1985. Plant injury has been observed with higher rates of Cygon and the phytotoxicity potential of this product is a severe limitation to its use.

Control of honeylocust pod gall midge has been highly variable. Granular formulations of Disyston, Furadan, and Temik have repeatedly failed to provide control. Greatest control (80%+

over 2 generations of the insect) has been achieved with liquid emulsions of Metasystox-R. Furadan 4F applied as a liquid emulsion has been intermediate in performance. Adequate watering to allow insecticide uptake has proved to be critically important.

The pinyon pitch mass borer has resisted control by use of soil applied (or injected) systemic insecticide. This insect causes an extreme disruption of the conducting tissue around the feeding site, preventing adequate uptake of the insecticide. Similarly, other insects which destroy the cambium (bark beetles, borers) are often reported to be poorly controlled unless treatments are initiated early in the infestation.

Therefore, the need for adequate water to allow insecticide uptake and poor translocation to disrupted tissues are key limitations for some uses of soil applied systemic insecticides. These insecticides are also translocated in greatest concentration to newest tissues which can prevent adequate control of species found on older wood. Furthermore, many of the insecticides with systemic ability are highly toxic to mammals and must be used in a very cautious manner.

Another aspect of certain systemi insecticides is their ability to affect the growt of the plant. Phytotoxicity can frequently occu from use of organophosphate types of insecticides particularly Cygon. Carbamate types o insecticides, (Furadan, Temik), frequently exhibi growth regulator activity. On certain vegetabl crops, promotion of flowering has been documente from treatment with these products. In 19 trials on nursery stock at the Colorado Stat Forest Service Nursery, transitory increases i growth were noted from treatment of two plan species. Five other species were not observed t have any growth response from treatment wit carbamate insecticides. Organophosphat insecticides have not been demonstrated to produc any growth rate increases in these plants whe pests were absent.

LITERATURE CITED

Cranshaw, W. S. 1985a. Use of soaps and detergents for insect control in Colorado. Colorado State University Extension Service-in-Action Sheet 5.547, 2p.

Cranshaw, W. S. 1985b. Honeysuckle witches bro aphid. Colorado State University Extension Service-in-Action Sheet 5.546, 2 p.

Greenhouse Production of Quaking Aspen Seedlings[1]

Karen E. Burr[2,3]

Abstract.--This paper describes the procedures for greenhouse production of container grown quaking aspen seedlings used at the Colorado State Forest Service Nursery in Fort Collins, Colorado. Topics include; seed collection and sowing, transplanting, thinning, exponential growth, hardening, pruning, grading, and a comparison of spring and winter crop growth rates.

INTRODUCTION

The Colorado State Forest Service Nursery in Fort Collins, CO, began greenhouse production of container grown quaking aspen (Populus tremuloides Michx.) seedlings on an experimental basis in the fall of 1983. Several crops have been grown since that time and many experiments have been conducted to improve the production process. The information presented here is a composite of the knowledge gained from those several crops and experiments, and represents the best methodology for producing quaking aspen seedlings developed thus far by the nursery.

SEED COLLECTION

The Colorado State Forest Service Nursery collects aspen seed rather than purchasing it, because large quantities of seed can be quickly collected from nearby sources in a good seed year. The seed will remain viable for several years when properly cleaned and stored.

Female aspen clones typically produce large quantities of non-dormant seed having 90 percent or greater gremination every 3 to 5 years (U.S. Department of Agriculture, Forest Service 1974). Seed matures late May to mid-June at 2350 m elevation west of Fort Collins and is collected just prior to release. When the capsules can be split open by hand fairly easily along the lines of suture and the seeds within are tan, rather than the pale green color of immature seeds, branches bearing catkins are pruned from selected seed trees and brought indoors. Seed shed and cleaning should be located in a clean, warm room with low relative humidity, low air movement, and minimal other concurrent uses.

The ends of the collected branches are recut and placed in water to keep the leaves from drying. Pieces of dried leaves are very difficult to separate from the seeds during the cleaning process. Supplying water to the branches also permits the capsules to continue developing, and seed release occurs within 7 to 10 days. Procedures for cleaning aspen seed with a series of soil screens have been described by Roe and McCain (1962). Their approach is improved with the use of a canister vacuum cleaner which can both collect the seeds once shed and supply the forced air needed for cleaning.

Seed moisture content is too high at the time of release for successful long-term storage. If the seed is allowed to come to equilibrium with the atmosphere by waiting 1 to 2 days before vacuuming and cleaning, no further drying measures are usually necessary. Seed moisture content of 6 to 8 percent of fresh weight permits 4 to 6 years storage in air tight containers at -18°C (Fechner et al. 1981, Wang 1973). Aspen seed can be maintained with freezer storage much longer than at storage temperatures above freezing (Benson and Harder 1972).

The quality of the seed, whether just collected or retrieved from storage, can be quickly checked. Radicle and hypocotyl elongation are evident in 48 hours from aspen seed sown on moist blotter paper in a covered petri dish at 20°C (McDonough 1979). It is best to determine seed

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quality prior to sowing or storing, as well as to monitor stored seed periodically.

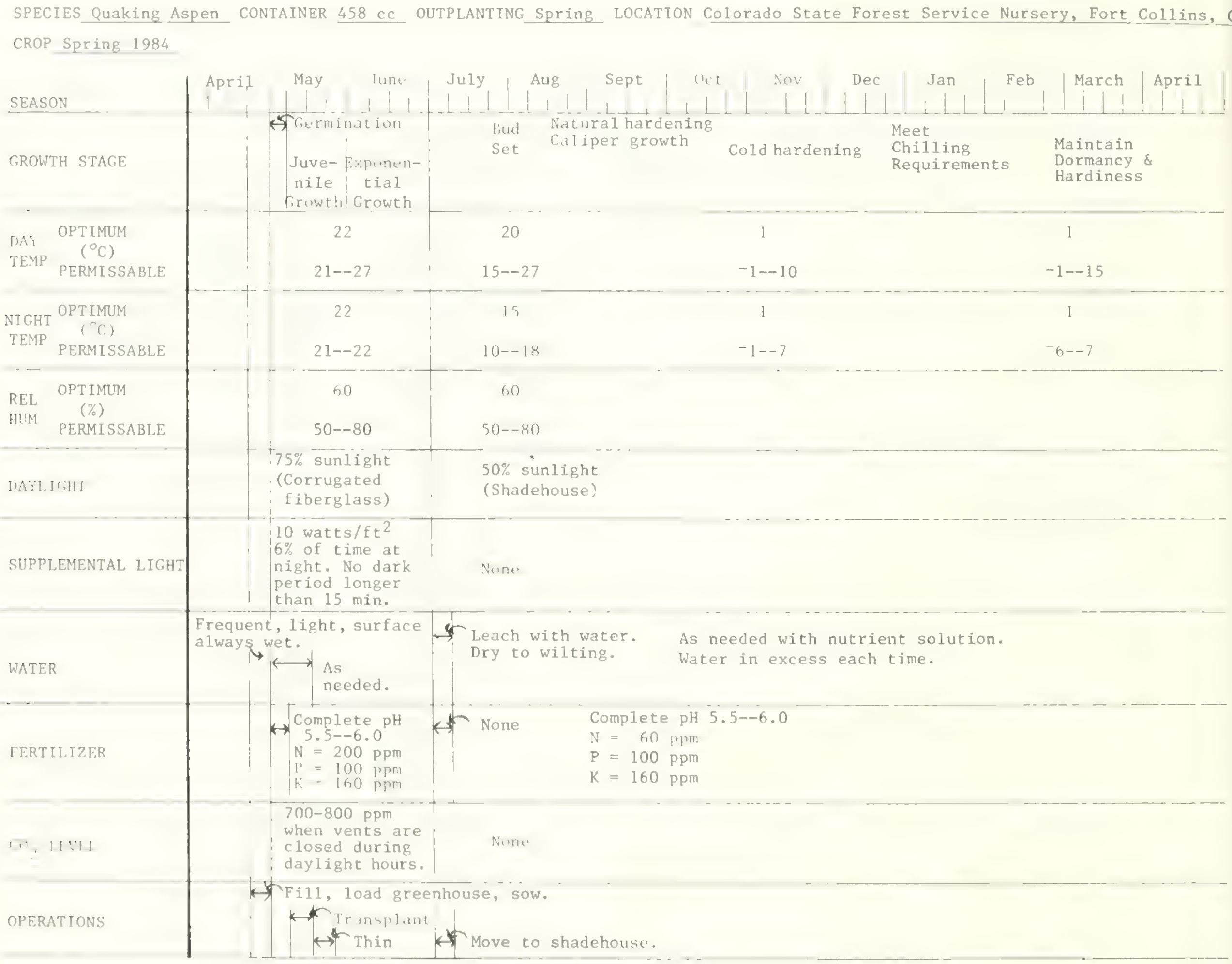
The cost incurred by the Colorado State Forest Service Nursery in 1984 for seed tree selection and monitoring, and seed collection and cleaning, was $2.20 per gram of pure seed. This is based on an hourly wage of $10 and the discontinuing of cleaning when a purity of at least 90 percent is reached. There were 5300 seeds per gram at a moisture content of 8.4 percent in this particular collection, as calculated from two samples of 50 seeds each.

SOWING

The greenhouses at the nursery are fully controlled with fan and pad cooling, overhead irrigation systems through which fertilizer is applied, supplemental CO_2, and intermittent lighting for photoperiod control. A standard greenhouse environment used for growing several species of containerized conifers at the nursery is also used for aspen production (fig. 1).

Aspen seed is sown directly onto dry Forestr Mix (W. R. Grace Co.) in Colorado Styro-Blocks (3, 458 cc cavaties) after the blocks have been machi filled with mix and moved to the greenhouse benches. Sowing is done by hand using a salt shaker with only one hole (1.5 to 2.0 mm diameter) open. An average of five seeds pass through the hole pe shake. This sowing rate is based on germination of 85 to 90 percent. The number of empty cavitie is too great if an average of 2 to 3 seeds are released because of a wide range in the actual number of seeds released each shake. Seeds can be sown with a salt shaker, one shake per cavity, at the rate of approximately 9000 cavities per hour.

No surface treatment is applied after the seeds are sown, such as the addition of a layer o perlite or grit. Seedling emergence can be inhibited by a sowing depth of only 2 mm (McDonough 1979). The Styro-Blocks are irrigated immediatel following sowing with the overhead mist system until soaked through and are then irrigated as need typically three times per day, to prevent the surface of the mix from drying during the first 12



SPECIES Quaking Aspen CONTAINER 458 cc OUTPLANTING Spring LOCATION Colorado State Forest Service Nursery, Fort Collins, CO

CROP Spring 1984

SEASON	April	May June	July Aug Sept	Oct Nov Dec	Jan Feb	March April
GROWTH STAGE		Germination Juvenile Growth Exponential Growth	Bud Set Natural hardening Caliper growth	Cold hardening	Meet Chilling Requirements	Maintain Dormancy & Hardiness
DAY TEMP (°C) OPTIMUM		22	20	1		1
DAY TEMP (°C) PERMISSABLE		21--27	15--27	-1--10		-1--15
NIGHT TEMP (°C) OPTIMUM		22	15	1		1
NIGHT TEMP (°C) PERMISSABLE		21--22	10--18	-1--7		-6--7
REL HUM (%) OPTIMUM		60	60			
REL HUM (%) PERMISSABLE		50--80	50--80			
DAYLIGHT		75% sunlight (Corrugated fiberglass)	50% sunlight (Shadehouse)			
SUPPLEMENTAL LIGHT		10 watts/ft^2 6% of time at night. No dark period longer than 15 min.	None			
WATER	Frequent, light, surface always wet.	As needed.	Leach with water. Dry to wilting. As needed with nutrient solution. Water in excess each time.			
FERTILIZER		Complete pH 5.5--6.0 N = 200 ppm P = 100 ppm K - 160 ppm	None Complete pH 5.5--6.0 N = 60 ppm P = 100 ppm K = 160 ppm			
CO_2 LEVEL		700-800 ppm when vents are closed during daylight hours.	None			
OPERATIONS	Fill, load greenhouse, sow.	Transplant Thin	Move to shadehouse.			

Figure 1.--Growing schedule of the spring 1984 crop of quaking aspen seedlings at the Colorado State Forest Service Nursery.

days. After that time, seedlings are irrigated with fertilizer approximately twice per week.

GERMINATION AND TRANSPLANTING

One week after sowing, germination is complete and seedlings are approximately 0.5 cm in height with cotyledons only. Seedlings reach an average height of 1.0 cm (range = 0.8 to 1.3 cm) and the first pair of true leaves is visible at the end of the second week after sowing. Root systems are fibrous and two-thirds the length of the above ground portion of the seedling at this time.

The aspen are transplanted from cavities with excess seedlings to empty cavities during the second week (fig. 2). Seedlings are lifted with the blade of a small knife and placed in a dibble hole in another cavity. An estimated 5 percent of the total cavities sown with a salt shaker require transplants, and much of the time required for transplanting is spent locating empty cavities. Cavities can be examined and the empty ones filled at the rate of 1800 cavities per hour. However, if empty cavities are already identified, transplanting at the rate of 300 seedlings per hour is possible.

Seedlings show no short term ill effects from transplanting, such as wilting, when transplanted at 1 cm tall. Transplanted seedlings (150) and non-transplanted seedlings (150) were monitored until reaching an average height of 51 cm to determine if there were any long term effects of transplanting. Seedlings transplanted at 1 cm tall were not significantly (p = 0.5) different in mean height, caliper, or mortality rate than non-transplanted seedlings thinned at 1 cm tall.

	Height cm	Caliper mm	Mortality %
Transplanted seedlings	53	4.1	7.3
Non-transplanted seedlings	49	4.0	5.3
Statistical test	t-test	t-test	Chi^2

Transplanting an entire crop from seed sown in flats is not recommended. Not only is it unnecessary for seedling estalbishment, but because the seedlings grow very fast, it is nearly impossible to transplant large numbers of seedlings before overcrowding in the flats adversely affects seedling morphology.

THINNING

Thinning to one per cavity is done early in the third week after sowing when the seedlings are at a height of 1.0 to 1.5 cm. Because the seedlings double in height, from 1.0 to 2.0 cm, during the third week, they are within this height range for only 3 to 4 days. It is extremely important to thin before the seedlings become taller than 1.5 cm. High seedling density affects seedling morphology very rapidly when seedlings within a cavity begin to compete as they increase in size. Early competition results in accelerated height growth associated with poor caliper development. Seedlings with this spindly form are unable to remain upright after irrigating because of the weight of the water on the foliage. Taller upright seedlings then suppress shorter ones.

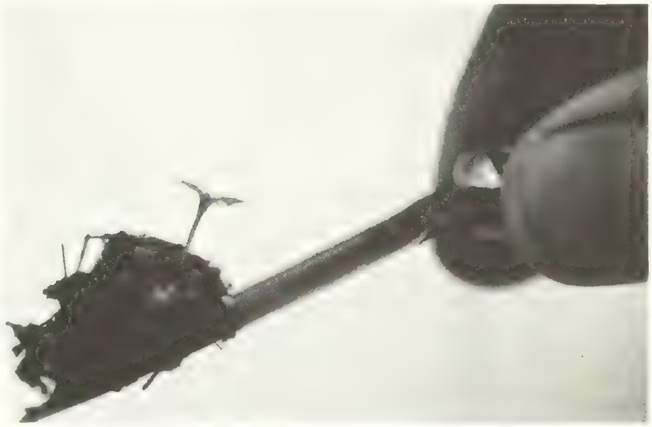


Figure 2.--Transplanting a quaking aspen seedling two weeks after sowing. Seedling height is 8 mm.

When determining how many aspen to sow at any one time, it is better to stagger the sowings than to sow more than can be thinned in a 4-day period. Seedlings can be thinned at the rate of 400 cavities per hour.

EXPONENTIAL GROWTH

Aspen seedlings sown in the greenhouse in spring or summer double in height the second, third, and fourth weeks after sowing, triple in height the fifth week, and then maintain a growth rate of approximately 1.5 cm per day until hardening is begun (fig. 3). Seedlings reach an average height of 45 cm in 8 weeks and average greater than 60 cm tall in 10 weeks. This rate of height growth is approximately twice that reported by others growing quaking aspen seedlings (Fisher and Fancher 1984, Okafo and Hanover 1978) and naturally established seedlings may require 4 years or more to reach an average height of 45 cm (Williams and Johnston 1984).

A major concern during this period of rapid growth is providing enough water to the roots. The leaves shed a great deal of water from the overhead mist system as the canopy closes. Large seedlings in the Styro-Blocks (fig. 4) need to be irrigated 1.5 to 2 hours to completely soak the

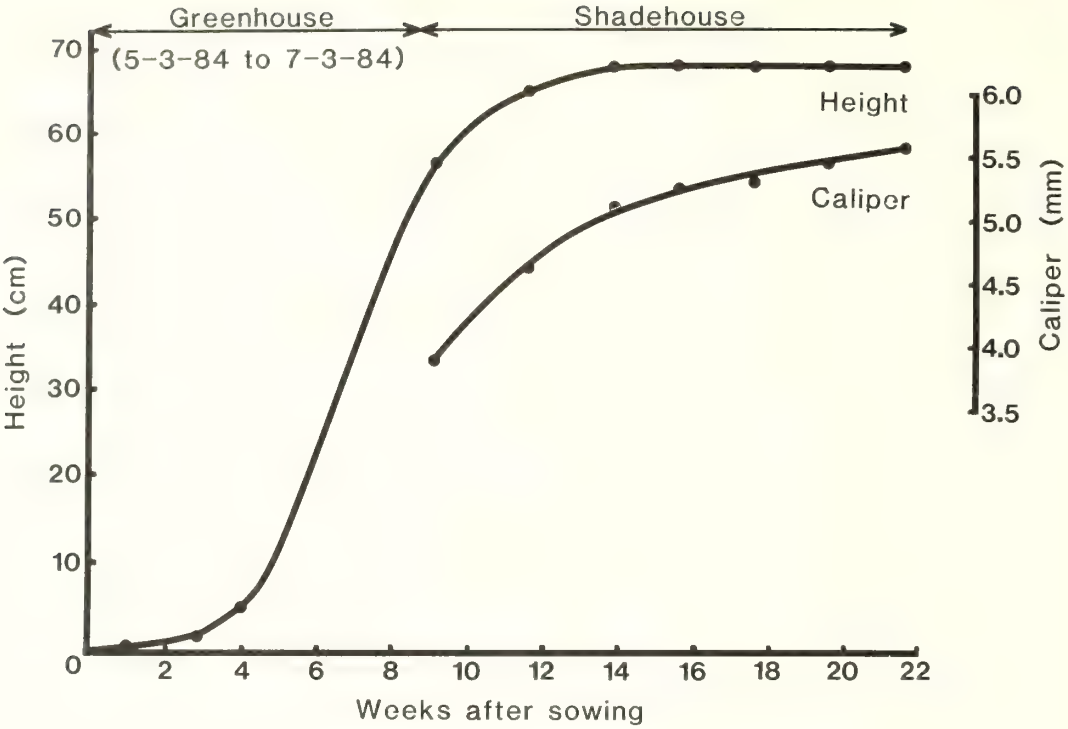


Figure 3.--Height and caliper growth of the spring 1984 crop of quaking aspen sown May 3, 1984. Seedlings were greenhouse grown until July 3, 1984 and then moved to a shadehouse for hardening. The rate of height growth between weeks 5 and 8 is 1.5 cm per day.

the containers. This is 3 to 4 times longer than is necessary prior to canopy closure. If the seedlings are not thoroughly irrigated, shallow root systems develop which can lead to frequent wilting, slowed growth, and the inability to grade seedlings because they cannot be removed from the containers with intact rootballs.

HARDENING

Spring and summer sown greenhouse crops are hardened, as well as overwintered, in shadehouses at the nursery. Actively growing aspen must be moved to shadehouses by early August in the Fort Collins area. Crops moved to shadehouses late August do not complete terminal bud development and have high mortality the following spring.

At the start of the hardening period, excess nutrients are leached from the containers and the seedlings are mildly drought stressed. The fertilizer is changed from high N/PK plus micronutrients to low N/PK plus micronutrients. Containers should be kept up off the ground until fall to allow adequate air pruning of the roots. Deer fencing around those areas of the shadehouses storing aspen is also necessary at the nursery.

Height growth of the spring 1984 crop (fig. 3), which was moved to the shadehouse July 3, 1984, stopped after 4 to 5 weeks in the shadehous. Final mean height was 68 cm. Extensive root system development followed. Caliper growth continued into October at which time the leaves turned color and abscised normally. Mean caliper in

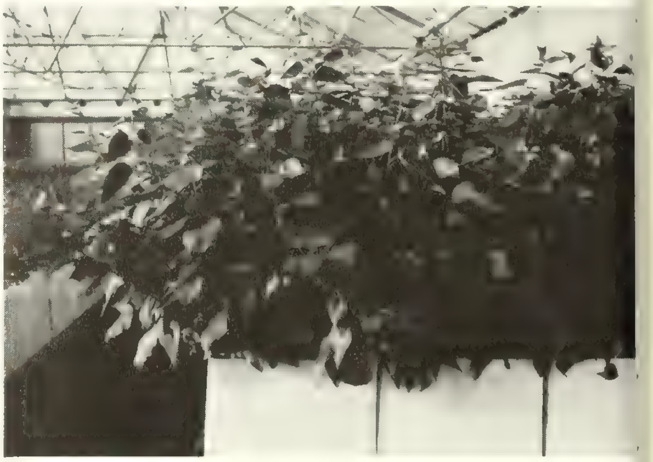


Figure 4.--Quaking aspen seedlings in Colorado Styro-Blocks at the end of the exponential growth phase. Average seedling height is 55 cm.

October was 5.54 mm. Lateral and terminal bud development were excellent. Overwintering mortality was less than 1 percent.

TOP PRUNING

Top pruning at the beginning of the shadehouse hardening period was tested as a means to stop height growth quickly and improve caliper development relative to unpruned seedlings. Results were the opposite. Eighteen Styro-Blocks of seedlings from the spring 1984 crop were pruned 2 days after being moved to the shadehouse (July 5, 1984) for comparison with the rest of the crop (692 unpruned Styro-Blocks). Average height was 57 cm prior to pruning and 27 cm after pruning. Average caliper of both groups was 3.9 mm at the time of pruning. Pruning induced lateral bud break and the pruned seedlings continued to put on top growth 2 weeks longer than the rest of the crop, thus delaying the hardening process. The caliper of the pruned seedlings 21 weeks after sowing (October 1, 1984) averaged 4.6 mm. This was significantly (t-test, p = .05) less than the caliper of the rest of the crop which averaged 5.5 mm at that time (fig. 3). If top pruning is necessary to reduce seedling height, it should be done after the seedlings are dormant.

Height reduction is best accomplished by shortening the period of time for accelerated greenhouse growth. The spring 1984 crop (fig. 3) was grown in the greenhouse for 61 days and reached a final average height of 68 cm. A crop sown in the summer of 1984 was grown in the greenhouse for 51 days and reached a final average height of 50 cm (fig. 5). Both crops were shadehouse hardened and had very similar height growth curves for the first 51 days. The 10-day difference in the growing period results in a substantial difference in final height because of the 1.5 cm per day height growth rate during the exponential phase.

GRADING

Grading is most efficiently done in the shadehouse after leaf abscission. The seedlings are easily handled and inspected then and the large majority of the season's root growth has occurred. Three criteria are used in grading. First, the seedling must be healthy. Second, the stem must be straight and upright, and within a fairly broad height range dependent upon the particular crop. Third, the root system must be extensive enough to permit intact removal of the seedling from the Styro-Block. Grading on the basis of caliper is infrequent because seedlings with poor caliper development also usually have poor stem form and inadequate root systems.

The number of seedlings that make grade is approximately 50 percent of the total cavities sown. Mortality is only 5.3 percent at the end of the exponential phase (see Transplanting tabulation). Thus nearly 45 percent of the cavities sown contain living seedlings at that time which will not make grade. The 45 percent cull rate is the result of seedling variability. To illustrate this, all 30 seedlings in a randomly selected Styro-Block from a crop 2 weeks into the hardening period were measured and ordered by height (fig. 6). Only the tallest 15 seedlings had sufficient caliper to remain upright without support from adjacent seedlings. The next 6 smaller seedlings had poor stem form and were being partially shaded and completely supported by adjacent seedlings. The smallest 9 seedlings, one of which had died (d), were completely shaded by taller seedlings and were growing intertwined among them or on the surface of the Styro-Block. Only the large dominant seedlings make grade at the end of the hardening period.

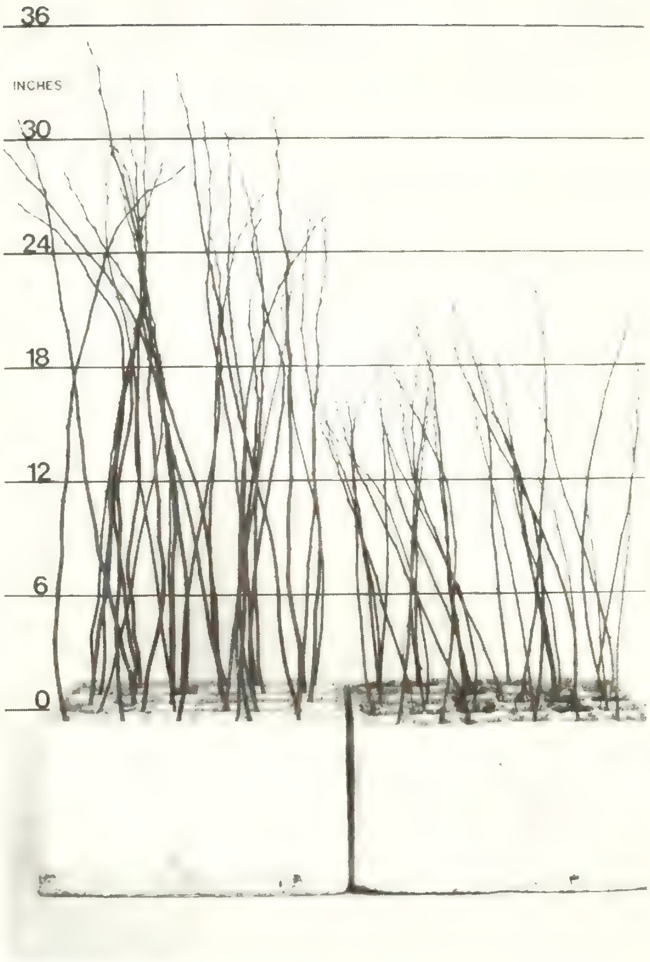


Figure 5.--Graded, dormant quaking aspen seedlings from the spring 1984 crop (left) and a summer 1984 crop (right). The hardening process was begun 61 days after sowing the spring crop and 51 days after sowing the summer crop.

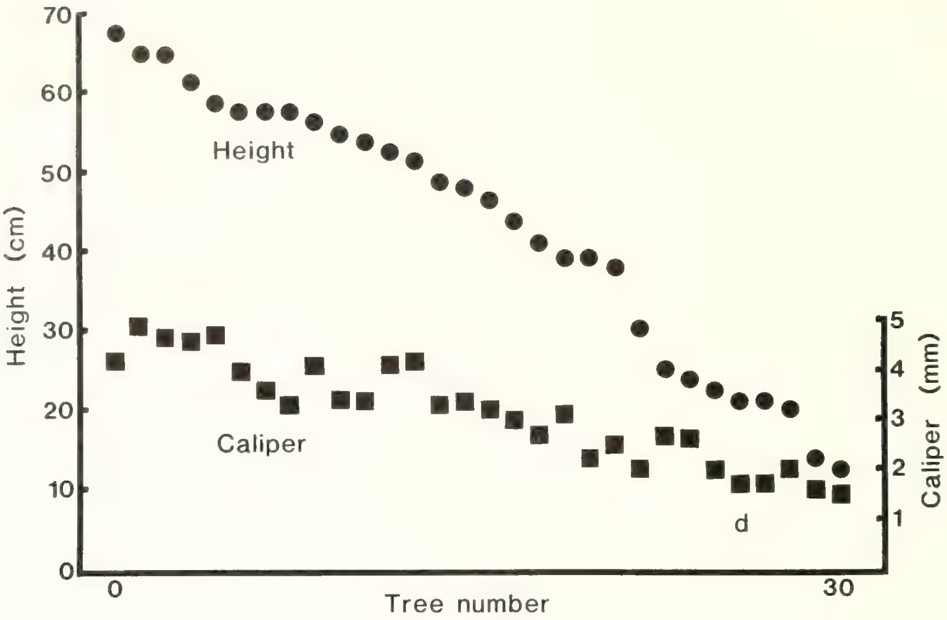


Figure 6.--Variability in seedling height and caliper two weeks into the hardening period within a single Styro-Block of 30 seedlings. One of the 30 was dead (d).

A method for producing a more uniform crop has yet to be developed. Slowing the growth rate by moving established seedlings from the greenhouse to the shadehouse for the majority of the exponential growth phase is being considered. Sorting the seedlings by size when 20 to 30 cm tall to reduce the competition should decrease the cull rate substantially. However, Styro-Blocks, being single 30-cavity units, are not amenable to this, and the seedlings cannot be removed from the blocks with intact rootballs until well into the hardening period.

WINTER CROPS

The growth of winter aspen crops can be as unpredictable as the weather. Growth rates are slower, relative to spring and summer crops, due to the shorter day length and lower light intensities. However, extremely slow rates are possible. The height growth of the winter 1984 crop (fig. 7), sown December 3, 1984, was similar to that of the spring 1984 crop (fig. 2) during the first 3 weeks following sowing. But the exponential growth phases of the two crops are drastically different. Ten weeks after sowing, the winter 1984 crop averaged only 10 cm tall while the spring 1984 crop averaged 60 cm tall. The weather during weeks 3 through 10 of the winter crop was unusually cloudy and the sharp increase in growth after the tenth week was associated with a concurrent improvement in the weather.

Such extreme variability in growth rates can cause scheduling problems. The extension of the time required for the exponential phase can result in a crop of the desired height but for whih there is no time remaining for the greenhouse hadening. The uncertainty of winter crops can be avoided without reducing the total number of seelings produced by growing two crops during the spring and summer months. With a maximum of 8 weeks greenhouse time required per spring crop,

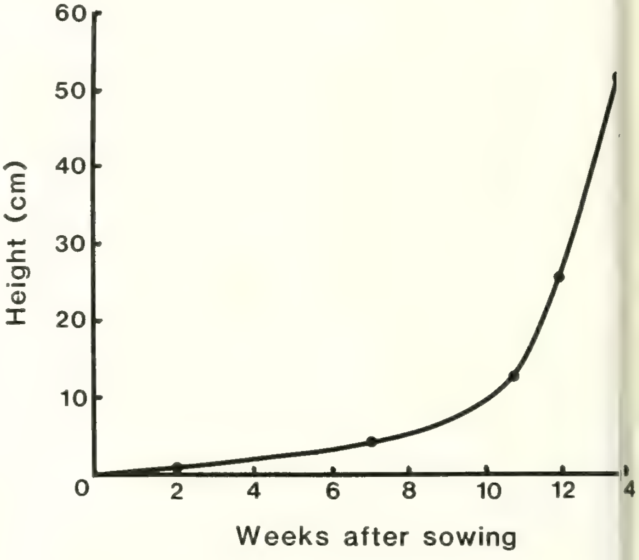


Figure 7.--Height growth, from sowing through the exponential growth phase of the winter 1984 crop of quaking aspen seedlings sown December 3, 1984.

wo crops can easily be grown in succession in ime to begin shadehouse hardening by August 1.

LITERATURE CITED

enson, M. K. and M. L. Harder. 1972. Storage of aspen seed. Genet, Physiol. Note No. 11. p. 1-4.

echner, G. H., K. E. Burr, and J. F. Myers, 1981. Effects of storage, temperature, and moisture stress on seed germination and early seedling development of trembling aspen. Can. J. For. Res. 11:718-722.

isher, J. T. and G. A. Fancher. 1984. Effects of soil amendments on aspen seedling production. In The challenge of producing native plants for the Intermountain area. Proc. Intermountain Nurseryman's Assoc. 1983 conference. Las Vegas, NV. Aug. 8-11, 1983. USDA Forest Service Gen. Tech. Rep. INT-168, 96 p.

McDonough, W. T. 1979. Quaking aspen--seed germination and early seedling growth. USDA Forest Service Res. Pap. INT-234, 13 p.

Okafo, O. A. and J. W. Hanover. 1978. Comparative root and shoot development of trembling and bigtooth aspen seedlings. p. 334-346. In Proc. Fifth North Amer. Forest Biology Workshop, Gainesville, FL. Mar. 13-15, 1978.

Roe, E. I. and D. P. McCain. 1962. A quick method of collecting and cleaning aspen seed. Tree Planters' Notes 51:17-18.

U.S. Department of Agriculture, Forest Service. 1974. Seeds of woody plants in the United States. Agric. Handb. No. 450. Shopmeyer, C. S., tech. coord. Washington, DC. USDA Forest Service, 1974. 883 p.

Wang, B. S. P. 1973. Collecting, processing, and storing tree seed for research use. Proc. IUFRO Int. Symp. Seed Processing. Bergen, Norway. Vol. I. Paper 17.

Williams, B. D. and R. S. Johnston. 1984 Natural establishment of aspen from seed on a phosphate mine dump. J. Range Mgmt. 37:521-522.

Fertilizer Trials on Containerized Red Pine[1]

Kent L. Eggleston[2] and Ruth Crownover Sharp[3]

Abstract.--Nitrate (NO_3), ammonium (NH_4), and urea forms of nitrogen fertilizers were tested on containerized red pine (Pinus resinosa, Ait.) at four locations in Michigan, Wisconsin, and Minnesota. Height, stem caliper, shoot and root dry weight, were all significantly different between treatments. Formulations with both high NO_3 and NH_4 produced larger seedlings at all locations at 14 weeks from sowing. Formulations with just high NH_4 Produced larger seedlings at three locations at 14 weeks old.

INTRODUCTION

Nearly 15 million containerized red pine, Pinus resinosa Ait. seedlings are planted annually on 18 to 20 thousand acres in Minnesota, Wisconsin, and Michigan. The success of these planting efforts depends greatly upon the ability of seedling growers to provide a seedling that will withstand the rigors of the environment.

Seedling growers from forest industry, government, and the private sector gathered in Escanaba, Michigan December 11-12, 1984 to explore ways to improve container stock quality[4]. All agreed that it would be beneficial to produce larger red pine container stock by either maximizing growth during the first 15 weeks in the greenhouse or by culturally controlling shoot height growth.

Red pine exhibits determinate height growth. Generally, 13 to 15 weeks after sowing, red pine seedlings stop shoot height growth and set bud even if environmental conditions are optimum for stem elongation. It is considered beneficial if taller, well balanced containerized seedlings could be produced during the 15-week growth period. Each greenhouse manager attending the Escanaba meeting gave a description of their cultural practices and stock specifications. All locations were similar in operation with only minor cultural practice differences except for on major difference; no two locations used the same fertilizers. A key question discussed was whethe nitrate (NO_3), ammonium (NH_4), or urea nitrogen plays a more important role in promoting shoot height growth.

The results of a cooperative study started b growers attending the Escanaba meeting are reported here. The objective of the study was to determine the effects of different nitrogen formulations on the development of containerized red pine seedlings grown under each cooperator's growing conditions. This study was also a pioneering effort to establish a pattern for future cooperative growers trials.

MATERIALS AND METHODS

Cooperators

The cooperating greenhouse facilities included two paper companies, one Federal facility, and one county government contracting with a private facility. The four cooperators an their greenhouse locations were Mead Paper Company, Escanaba, Michigan; Consolidated Paper Company, Monico, Wisconsin; Forestry Sciences Laboratory (FSL), Rhinelander, Wisconsin; and Cas County Land Department, Carlson's Greenhouse in Cass Lake, Minnesota (figure 1).

Container

The seedlings were grown in Styroblock 2-A containers at all locations. This container is a rectangular block of expanded polystyrene containing 240 cone-shaped cavities with a cell density of 103 cavities per square foot. Each cavity is 2.5 cubic inches with a top diameter of 1 inch and a depth of 4.5 inches.

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[1] Paper presented at Intermountain Nurserymen's Association meeting, Fort Collins, Col., August 13-15, 1985.

[2] Kent L. Eggleston, Horticulturist, North Central Forest Experiment Station, St. Paul, Minn.

[3] Ruth Crownover Sharp, Forestry Technician, Ouichita National Forest, Mount Ida, Ark.

[4] Scholtes, John R. Container Grower's Meeting minutes, December 11-12, 1984 in Escanaba, MI. Minutes being assembled at State and Private Forestry, Broomall, Penn.

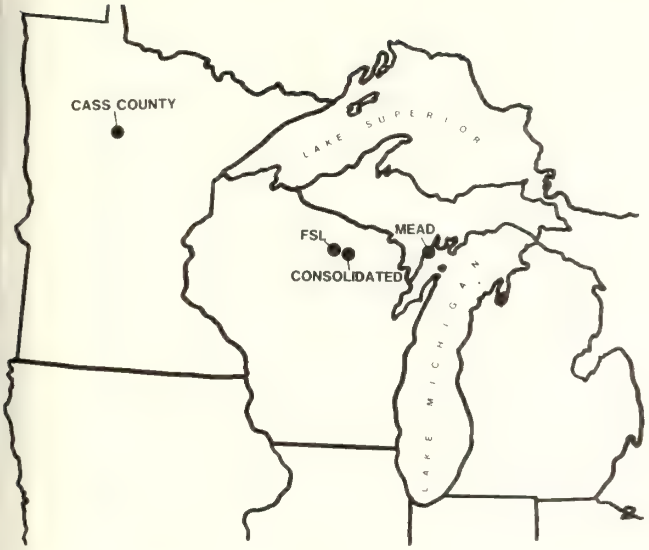


Figure 1.--Map of Cooperator locations.

Treatment Procedure

Cultural practices for red pine production were identical for all locations except for fertilizer treatments. There were five fertilizer treatments: three standard fertilizers supplied to all locations, and a fertilizer selected by each grower was applied both by hand, and by the grower's production method. The four participating Nurserymen received the same three standard fertilizers, sampling diagrams, mailing bags, and instructions to standardize the three treatments and sampling procedures. The standard fertilizers were measured, mixed in watering cans, and hand applied at all locations. These standards were 20-10-20 (12% NO_3-N, 8% NH_4-N) referred to hereafter as NO_3 (Nitrate), 17-6-6 (17% NH_4-N) referred to hereafter as NH_4 (Ammonium), and 20-19-18 (5.2% NO_3-N, 3.75% NH_4-N, 11.75% urea) referred hereafter as urea (table 1).

In addition, each grower also applied his own in-house fertilizer mix to selected container blocks by hand (treatment designated T-1) and also to the rest of the greenhouse, including three more selected blocks through the production injector-irrigation system (treatment designated T-2). T-1 and T-2 application rates were determined by each grower to simplify his particular stock nutrition needs. growers were encouraged to keep the total N of their selected treatments close to that used for the three standard fertilizers to achieve the best comparison.

When the production stock, including the three selected T-2 treatment blocks, were being fertilized the other treatment blocks were either removed from the area or shielded. After fertilizing all seedlings were rinsed during the water-only portion of the fertilization-irrigation routine.

Each grower determined when to water and fertilize. Some used every-other-day fertilizer schedules. Others established their schedules by monitoring seedling needs and applying when necessary, usually during the exponential growth stage which was from approximately 6 weeks to 14 weeks after sowing. During the first 6-week juvenile growth period, the fertilizer rates were half those shown in Table 1.

Table 1.--Nitrogen constituents in treatments at various locations.

Treatments (by location)	NPK	NO_3	NH_4	Urea	Total N
		ppm			
NO_3[1])	20-10-20	182	122	0	304
NH_4)-all locations	17-6-6	0	258	0	258
urea)	20-19-18	80	57	168	305
FSL T-1, T-2[2]	20-7-19	176	106	21	303
Mead T-1	20-10-20	182	122	0	304
T-2	20-10-20	158	106	0	264
Cass Co. T-1, T-2	10-20-30[3]	77	19	0	96
Combined -------	34-0-0	23	7	0	30
Consol. T-1, T-2	20-20-20	51	36	95	183

[1] NO_3, NH_4, and urea are the standard fertilizer mixes used at all locations.
[2] T-1 and T-2 are the local greenhouse fertilizer treatment applied by hand (T-1) and through the irrigation system (T-2).
[3] 10-20-30 is a nutriculture product, produced by Plant Marvel Laboratories, Chicago, IL. The remaining 5 formulations are Peters soluble fertilizer produced by Grace Horticultural Products Technical Group, Fogelsville, PA.

(Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.)

Experimental Design

At each location, experiment consisted of a randomized block design with three replications. All replications were in the same greenhouse. The T-1, NO_3, NH_4, and urea treatments were each randomly assigned to one styroblock per replication. The three T-2 sample styroblocks were selected from production stock that typified the average stock type of the crop.

Sampling and Data Analysis

A standard sampling design was supplied to each grower for selecting seedling samples biweekly beginning 4 weeks after sowing. Seedlings from each location were kept separate by treatment and replication. Each location sent the seedlings in the supplied mailers to the Rhinelander FSL to be measured, oven dried, weighed, and recorded. Data from all locations were contained and analyzed by ANOVA. Variables analyzed were height, stem caliper, shoot dry weight, root dry weight, and shoot/root dry weight ratio. Included in the model were effects of location, treatment, time, and three two-way interactions. Effects due to replications and replication interactions were combined into a pooled error term. Significance was tested assuming all effects fixed which allowed using the error mean square as the denominator in all F-tests.

RESULTS

In general, main effects were stronger than interactions although interactions were themselves highly significant. Effects due to treatments were stronger than effects due to location for all variables. The fact that interactions were significant suggests that treatments need to be selected on a site-by-site basis in order to maximize growth. No one treatment at 14 weeks old was best at all locations (figure 2).

All seedling/characteristics showed similar responses to fertilizer treatment (figure 3). For example, the urea treatment at the Cass County location produced the poorest seedlings, in terms of characteristics, measured; the T-2 treatment tended to produce the best seedlings.

Responses at the other locations showed similar patterns for 14-week-old seedlings (table 2).

Comparing the standard treatments at the four locations revealed several patterns (figure 4). urea produced the shortest shoots and smallest stem calipers (except for the FSL location). The NH_4 ammonium treatment unexpectedly produced the best seedlings (again, except for shoot height at the FSL location). At three locations, the NH_4 treatment did better than the growers' preferred production treatment, T-2.

DISCUSSION

Some growers learned that other available commercial fertilizers may produce better

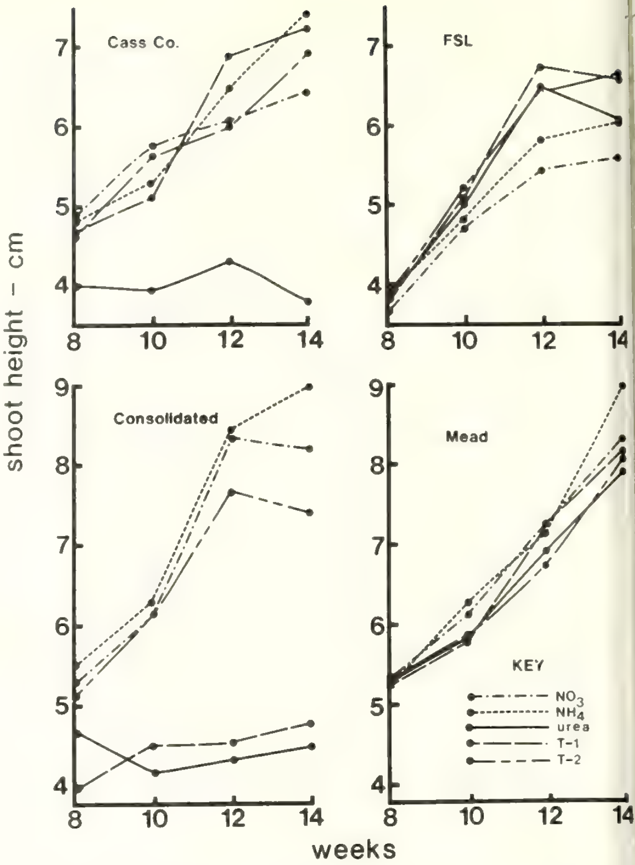


Figure 2.--Containerized red pine shoot height response to fertilizer treatments at various greenhouse locations.

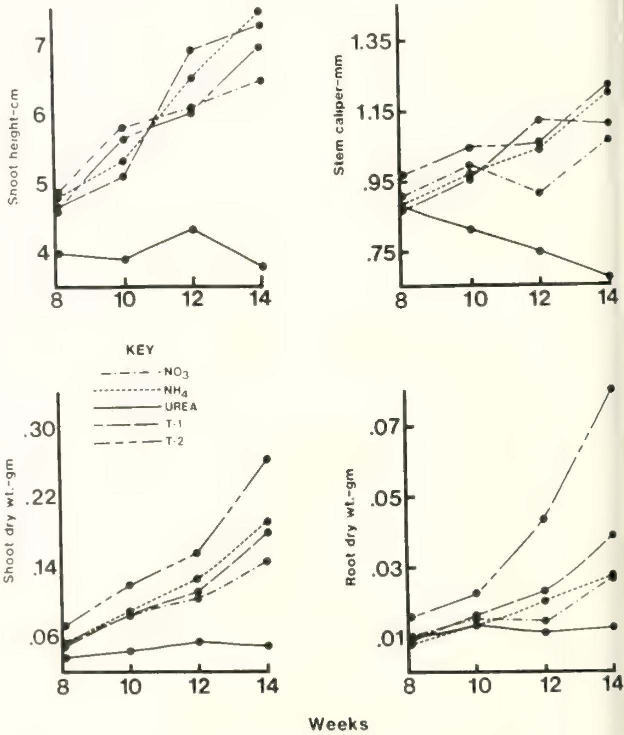
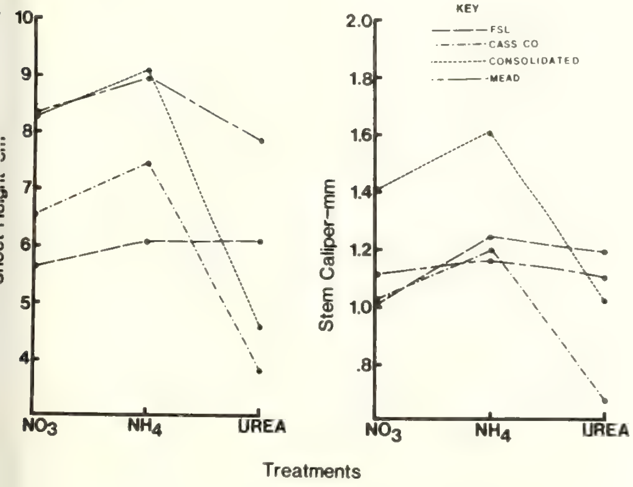


Figure 3.--Containerized red pine physical characteristics by fertilizer treatments at Cass County greenhouse location.

Table 2.--Seedling characteristics at 14 weeks by each location and fertilizer treatment.

	FSL	Mead	Cass County	Consolidated
Stem Height (cm)				
NO_3	5.56	8.28	6.48	8.21
NH_4	6.03	8.90	7.40	9.00
urea	6.06	7.87	3.80	4.50
T-1[1]	6.56	8.08	7.22	4.79
T-2	6.60	8.10	6.90	7.42
Stem Caliper (mm)				
NO_3	1.02	1.30	1.06	1.40
NH_4	1.25	1.37	1.19	1.60
urea	1.19	1.32	0.67	1.02
T-1	1.24	1.38	1.11	0.96
T-2	1.26	1.10	1.21	1.30
Shoot Dry Weight (gm)				
NO_3	.173	.194	.145	.281
NH_4	.295	.206	.188	.356
urea	.252	.180	.048	.106
T-1	.289	.193	.177	.105
T-2	.289	.134	.262	.250
Root Dry Weight (gm)				
NO_3	.046	.058	.026	.101
NH_4	.065	.053	.027	.138
urea	.071	.054	.012	.051
T-1	.074	.057	.038	.044
T-2	.095	.059	.080	.108
Shoot/Root Dry Wt. Ratio				
NO_3	3.8/1	3.3/1	5.6/1	3/1
NH_4	4.5/1	3.9/1	7/1	2.6/1
urea	3.5/1	3.3/1	4/1	2/1
T-1	3.9/1	3.4/1	4.7/1	2.4/1
T-2	3/1	2.3/1	3.3/1	2.3/1

[1] T-1 and T-2 are the local greenhouse fertilizer treatments, hand applied (T-1) and applied same as for greenhouse production (T-2).



igure 4.--Fertilizer treatment effects at various greenhouse locations at 14 weeks from sowing.

seedlings than their currently preferred ones. Since three treatments were standard across locations but the treatment responses differed by location, it is clear that fertilizer response depends upon environmental conditioning. To maximize seedling growth, each grower should conduct fertilizer trials periodically to test performance against changes in cultural practices, or to test new fertilizer mixes; an observation worth noting as a grower with multispecie production; the fertilizer treatments that produced better red pine seedlings did not produce better jack pine seedlings. There appears to be specie specific responses to fertilizer that require testing to maximize seedling performances. Results from other growers' trials may not necessarily apply.

The plan for this study, which involved several growers providing data from standard tests with overall coordination provided by a research organization, worked satisfactorily. Thus, the second goal, to develop a pattern for future cooperative trials with area container growers, was achieved.

REFERENCES

Foster, W. J., R. D. Wright, M. M. Alley, and T. H. Yeager. 1983. Ammonium absorption on a pine-bark growing medium. J. Amer. Soc. Hort. Sci. 108(4):548-551.

Gardner, A. C. 1977. A three level nitrogen phosphorous trial to determine optimum fertilizer levels for jack pine container stock. Thesis. Lakehead University, School of Forestry. 16 p.

Lackey, Michelle, and Alvin Alm. 1982/3. Evaluation of growing media for culturing containerized red pine and white spruce. Tree Planters' Notes. 7 p.

Peters Fertilizer Spectometer. 1981. Analysis Manual. W. R. Grace and Company. 138 p.

Phipps, H. M. 1974. Growing media affect size container-grown red pine. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN, Research Note NC-165.4

Van Den Driessche, R. 1971. Response of conife seedlings to nitrate and ammonium sources o nitrogen. Plant and Soil 34(2): 421-439.

Yeager, T. H., and R. D. Wright. 1982. Does nitrogen outweigh phosphorus in influence o plant growth? American Nurseryman. 2 p.

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Stratification and Germination of Western White Pine Seeds[1]

Rodger Danielson[2]

Abstract.--Techniques of stratifying Western white pine seeds were compared as was length of stratification. Speed of germination increased with increased stratification periods. Layered peat moss stratification and stratification on top of peat/vermiculite substrate were equally effective. Soaking seeds in water prior to layered peat stratification and layering dry seeds produced conflicting results, indicating a need for further study.

INTRODUCTION

Western white pine is an important timber species of the Western United States. Although germination methods have been published in both U.S. and international seed testing rules, the species is very dormant and often firm, ungerminated seeds remain at the conclusion of laboratory germination tests.

Firm seeds are dormant and indicate that pretreatment has not been sufficient to overcome seed dormancy. Even after very lengthly stratification periods, dormancy is not always overcome. Seeds of Western white pine have been reported to germinate in the nursery bed a year after sowing (Kathy Wolfe, 1985, personal communication).

Investigators have begun to look at alternative and more effective methods of pretreating Western white pine seeds. For example, a method utilizing laundry bleach was shown to increase germination and reduce stratification time by 50 percent (Advincula, et al, 1983). A combination of warm and cold stratification was also reported as being effective in overcoming dormancy in Western white pine seeds (Anderson & Wilson, 1966).

J. Herbert Stone Nursery stratification procedures for Western white pine seeds involves soaking seeds in water for 48 hours and then layering the seeds in nylon mesh bags between peat moss at 3C for 13 weeks. They have used this same procedure in their seed laboratory and believe that it gives more rapid germination results than those obtained when following AOSA rules.

This paper is a preliminary report of a cooperative study between J. Herbert Stone Nursery and Oregon State University Seed Laboratory to evaluate the J. Herbert Stone Nursery procedure as a laboratory method for measuring seed germination. It was felt that if stratification procedures between the laboratory and nursery were the same, laboratory results may more closely predict actual field emergence. In addition, it was hoped that speed of emergence would improve, resulting in lower firm seed counts at the conclusion of the germination test.

MATERIAL AND METHODS

Ten seed lots of Western white pine harvested in 1984 from locations throughout Oregon were used in this study. Seeds were tested immediately after extraction and cleaning without any storage period. Germination tests were conducted by placing seeds on media contained within covered plastic boxes measuring 12 cm square x 2.8 cm deep. Each germination treatment consisted of four replicates of 50 seeds. Germination media was a peat/vermiculite mix. Germination temperatures were alternating 20-30C with cool white fluorescent light during the 8 hour 30C period; constant 25C with 16 hours of light daily; and room temperature with 16 hours of light daily. Light at 25C and room temperature was from Sylvania Grow-lux fluorescent tubes. Stratification was conducted by imbibing seeds on top of a peat/vermiculite mix or by layering dry and presoaked seeds between wet Canadian sphagnum peat moss. Seeds that were soaked were placed under running tap water for 48 hours at room temperature. Stratification temperature was 3C. Germination counts were made every 7 days up to 49 days. Remaining ungerminated seeds at the Oregon State University laboratory were cut to determine presence of firm seeds. AOSA Rules for Testing Seeds (1981) were used to evaluate seedlings. Design of the experiment was a split plot.

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[1] Paper presented at the Intermountain Nurseryman's Association Meeting, Holiday Inn Convention Center, Fort Collins, Colorado, August 13-15, 1985.

[2] Rodger Danielson is Senior Instructor, Crop Science Department and Manager, Oregon State University Seed Laboratory, Corvallis, Oregon.

Table 1.--Percent germination at 28 and 49 days of western white pine seeds stratified on top of and layered between media following soak and no soak treatments. Germination temperatures were 20-30 and 25C. (OSU data)

	Seeds imbibed on top of peat/vermiculite				Seeds layered between peat			
	20-30C/8 hr light				25C/16 hrs light			
	No soak				No soak		48 hr soak	
	8 wk ch		13 wk ch		13 wk ch		13 wk ch	
	28	49	28	49	28	49	28	49
3903	3	[illegible]	17	59	70	78	83	89
4837	12	[illegible]	76	83	41	61	65	79
4838	20	38	52	67	35	50	50	69
4839	21	55	70	79	43	69	65	80
4840	6	42	29	63	22	57	32	55
4841	30	64	62	78	43	79	58	82
6003	31	69	76	85	29	44	54	63
6004	15	54	62	50	26	58	38	59
6005	1	42	13	40	14	24	30	39
6006	-		33	67	6	21	29	42
X	16.9	49.1	48.5	70.1	32.9	54.1	50.4	65.7
X Firm seeds*	-	36.7	-	19.3	-	33.4	-	22.4
X Viability**	-	85.8	-	89.4	-	87.5	-	88.1

* Firm seed refers to firm ungerminated seed.

** Viability refers to total germination plus firm ungerminated seed.

Table 2.--Percent germination at 28 and 49 days western white pine seeds stratified layered b tween peat moss following soak and no soak treatments. Germination temperature was room temperature. (J. Herbert Stone data)

Sample #	Room temperature/16 hrs light			
	No soak 13 wk chill		48 hrs water soak 13 wk chill	
	28	49	28	49
3903	34	77	34	66
4837	61	86	27	64
4838	19	68	39	64
4839	45	73	35	61
4840	7	52	23	48
4841	45	79	31	74
6003	39	73	31	63
6004	16	63	42	74
6005	12	40	13	28
6006	9	32	11	32
X	28.7	64.3	28.6	57.4

Data was analyzed at the 5% level using both a paired t test and analysis of variance.

RESULTS AND DISCUSSION

Data in Table 1 summarizes Oregon State University results of this study. Total viability, including percent germination plus firm ungerminated seed, remained relatively constant regardless of the treatment. Viability of the seed lots was near 90 percent.

Speed of germination increased with longer stratification periods. Average germination at 28 days was about 17 percent after 8 weeks stratification compared to figures double that after 13 weeks stratification. Speed of germination was not greatly affected by method of stratification. It was felt that stratification in peat moss would increase speed of germination. Only one sample showed a significant response to stratification treatment. Germination percent of sample 3903 was 83 at 28 days when soaked and stratified in peat compared to only 17 percent when seeds were stratified on top of media. One sample showed significantly higher germination at 28 days following stratification on top of media than when soaked and stratified between peat moss. Sample 6004 germinated 62 percent at 28 days following stratification on top of media compared to 38 percent when soaked and stratified between peat moss.

Soaking seeds prior to stratifying between peat increased both speed of germination and total germination on tests at the Oregon State University laboratory, but not at J. Herbert Stone. Average Oregon State University germination results of soaked seeds at 28 days was about 50 percent compared to about 33 percent without soaking (Table 1). Results at J. Herbert Stone (Table 2) were almost identical regardless of treatment. Their average germination percent without soaking prio to stratification between peat moss was 28.7 compared to 28.6 when seeds were soaked prior to stratification between peat moss.

Similar studies are being conducted on the same seed lots after having been in frozen storage for 6 months. To date the results of tests on seeds without storage indicate that speed of germination increases with increased length of stratification. No one method of stratification produced superior results. Stratification procedures used at the Oregon State University Seed Laboratory compared favorable with nursery practices at J. Herbert Stone Nursery. Additional testing will be required to determine whether soaking prior to stratification in layered peat moss influences speed of germination.

LITERATURE CITED

Advincula, B.A. et. al. 1983. A method for germination of Western white pine seeds. Pape presented at Western Forestry & Conservatio Association Conference, December 12-14, 198 Portland, Oregon.

Andersen, H.W. and B.D. Wilson. 1966. Improved stratification procedures for Western white pine seed. State of Washington Department of National Resources Report Number 8.

Association of Official Seed Analysts. 1981. Rules for testing seeds. Journal of Seed Technology 6(2):1-125.

Wolfe, Kathy. 1985. Personal communication. USDA Forest Service, J. Herbert Stone Nursery, Central Point, Oregon.

Development of Underground Cold Storage at Pine Ridge Forest Nursery[1]

J. Roger Hamilton[2]

Abstract.--Three 72 foot (21.6 m) squash culverts were buried under 5 feet (150 cm) of soil at an especially selected site at Pine Ridge Forest Nursery, Alberta, Canada. The culverts were flooded with ice in the winter and provide a passive refrigeration cold storage unit for 2.5 million seedlings.

INTRODUCTION

In 1980, the Alberta Forest Service started a reforestation program called Maintaining Our Forests. The objective of this program was to reforest old burns and convert off site aspen to conifer forests, in order to make up for lands lost to agricultural and petrochemical expansion in Alberta's green zone.

At that time, Pine Ridge Forest Nursery was asked to develope the necessary plans and infrastructure to increase its production from 10 million container seedlings to 20 million and 10 million bareroot seedlings to 18 million.

Part of the increase in bareroot production meant that additional cold storage for bareroot seedlings would be necessary. The conventional cold storage at Pine Ridge Forest Nursery could hold 12.5 million seedlings, leaving a balance of 5.5 million seedlings to be stored or otherwise hot lifted etc.

OBJECTIVES

Several objectives were set for the cold storage addition:

1. The storage structure should hold 2.5 million trees.
2. The storage structure should be built at least cost and have a low maintenance and running cost.
3. This project would be a prototype for field satellite storage.

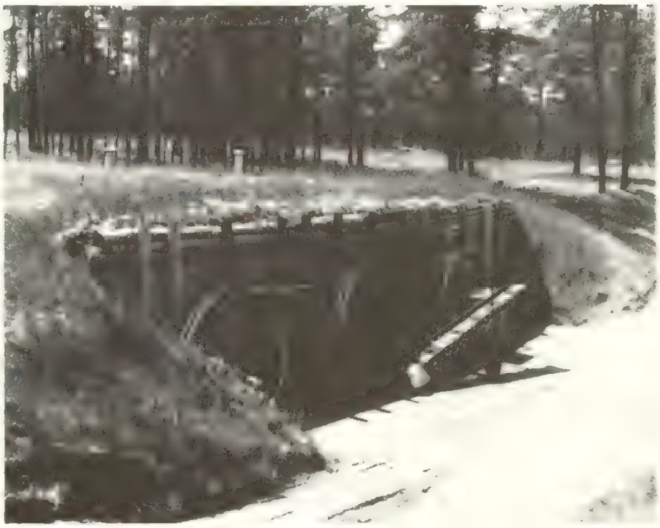

Figure 1.--Culvert installation at Pine Ridge.

Keeping these objectives in mind, several alternatives were looked at. As a result, snow caches, ice houses and root cellars were investigated. Our forefathers used the concept of root cellars and ice houses for cold storage and preservation for many years, so we thought that a combination of the two concepts would meet all our above-noted objectives. During construction of the seed processing system, the seed cold storage building at Pine Ridge was placed underground. It was discovered that 4 feet (120 cm) underground, providing the surface is never disturbed, the soil had a constant temperature of +39°F (+4°C). Cooling in summer and heating in winter was very inexpensive. Another added feature was the constant temperature of the soil and large masses of soil meant that the temperature would change very slowly if a power failure occurred. Some work had been done in the past with ice in culvert structures, but this was above ground.

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[1] Paper presented at Intermountain Nurserymens Association meeting (Fort Collins, Colorado, August 13, 14-15, 1985).

[2] J. Roger Hamilton is Production Forester, Alberta Energy and Natural Resources, Alberta Forest Service, Pine Ridge Forest Nursery, Smoky Lake, Alberta, Canada.

Putting all of the foregoing together it was decided to bury squash multi plate culverts underground with 5 feet (150 cm) of soil over them. In the dead of winter, the culverts would be flooded until a foot of ice was built-up. Trees would be moved in on pallets on the ice and stored until spring. It was hoped that the ice would last until the end of the shipping season, around the first of July.

A squash culvert design was choosen as the nursery's bareroot boxes can be stacked only six high before the bottom box starts to collapse. Thus height for the ice, pallets and boxes should not exceed 8 feet (2.4 m). Culvert suppliers were consulted and the widest squash culvert of 8 feet (2.4 m) height was 13 feet (3.99 m). This set the width parameter. In order to store 2.5 million trees at 500 trees per box, and using our height and width specifications, a total length of culvert of 216 feet (64.8 m) was derived. It was decided that this length was impractical for a single culvert. The length was divided in three and thus three 72 foot (21.6 m) culverts were installed.

A survey of the nursery site was done at this time, looking for a gulley or depression where these culverts could be installed facing north (shading doors). A suitable site near the north fence was found that had a shaded depression big enough for the three culverts with suitable drainage and allowing for a road to be built for access by a semitrailer truck and 45 foot (13.7 m) reefer van.

Department of Highways bridge branch was consulted, and it was found out that most of these large culverts are bid installed by the manufacturer. Thus tenders for the culverts were let.

CONSTRUCTION

All the excavation work was done using the Nursery's D6 cat. The site had been a dump for waste sand and ash from the nursery clearing. An area 55 feet (16.5 m) by 80 feet (24 m) had to be dug out and levelled. A bed of sand 1 foot (30 cm) thick was laid for each culvert. The bed had to have a very slight grade at 1 percent to provide drainage and was made of sand and/or gravel to prevent the culverts from shifting. At this point, the erection crew came in and installed the culverts. Each culvert was spaced about 8 feet (2.4 m) from the other. Erection took a day per culvert.

Once the culverts had been installed and checked, construction of the back wall commenced. Native pine from the nursery site which was peeled and treated to prevent rot and backed by a 3/4 inch (19 mm) plywood with steel bracing was used for the wall.

Backfilling had to be done very carefully in order to prevent distortion of the culverts. Sand was placed in 6 inch (15 cm) layers and tamped. Layers had to be placed evenly. This had to be done until backfilling was "over the hump" on the sides of the squash culverts. At that point, a large front end loader with a 12 yard bucket was brought in to complete the job until 5 feet (150 cm) of soil covered the culverts.

In the front, three telephone poles were cemented in an upright position between each culvert. Then logs were placed horizontally to form a front wall. Deadman logs were placed between the culverts and cable installed to hold the tops and center of the telephone poles in place.

Double airlock doors were installed, with the inner door having 4 inches (10 cm) of styrofoam for insulation. Air vents were installed in the roof at 1/3, 2/3 and at the end. A manifold was built at the end and a fan used in the winter to increase air circulation during freezing.

Each culvert had a water pipe with spaced nozzles installed in the roof. A water truck is hooked up to the water pipe in the winter and flooding can be completed in a matter of minutes.

The final phase of construction was landscaping the site to channel spring run-off away. A leaching pit was constructed in the roadway by the doors to collect run-off from rain and snow melt. The site was seeded to grass and planted with trees to prevent erosion. The site is to remain undisturbed.

COST

The following is a summary of the costs of building the three culverts:

Culverts and assembly (bid price)	$ 42,233.00
Wages	13,963.00
Materials and supplies	453.00
Administration costs	2,882.00
Equipment operating costs	4,206.00
Total Construction Costs	$ 63,737.00

OPERATION

The culverts were flooded for the first time in the winter of 1983/84. Freezing weather occurred in the first part of November and the doors were opened and a temperature monitor was installed. The first thing that was noticed was that the air temperature did not come down below freezing despite temperatures on the outside that were well below freezing. A circulating fan was installed and cold air blown into the culverts. Slowly the temperature decreased until by early December, ice making could commence. In order to make ice properly, a thin layer of water had to be sprayed over the interior to seal all the cracks before larger amounts of water could be laid on. Even then it was discovered that only a 1/2 inch (1 cm) of water could be flooded on the ice at a me as thicker layers melted the seal and took long time to freeze.

By mid January, air temperatures had decreased om +28°F (-2°C) to +25°F (-4°C) and a foot of e had built-up. The doors were closed and a ydrothermograph probe installed so we could onitor the inside air temperature. Air emperatures were +28°F (-2°C) all winter despite e -40°F (-40°C) outside temperatures experienced.

Toward the spring several hundred boxes of areroot trees were taken from the conventional old storage and placed on pallets in the culverts. emperature probes were installed and the trees ere held till spring planting. Temperatures in he box stayed from +28°F (-2°C) to +32°F (0°C) ntil outplanting. A trial outplanting was onducted in May of 1984, and the trees showed ood regeneration potential.

The empty culverts were sealed until mid-ummer 1984 when some modifications to the rrigation and air circulation system were made. ven in mid August the culverts still had ice emnants in them.

In November 1984 the culverts were again ade ready for use. Ice was slowly built-up ver time until a foot of ice was on the floor. n March 1985 all three culverts were loaded up ith bareroot from conventional cold storage and xtracted containers were added in late March. n box temperatures again remained at +28°F (-2°C) to +32°F (0°C) during storage until spring planting in May.

At the end of shipping, the doors were again closed and the intervening space was filled with bagged vermiculite. It is hoped that ice will be retained year round if proper care is taken to reduce air circulation.

CONCLUSIONS

It appears at this time that all our objectives have been met. An inexpensive, effective cold storage alternative has been proven to be a reality. Tree quality seems to be excellent after storage in this structure. The large mass of soil around the culvert acts as an excellent cold sink in that it is very slow to cool off, and alternately, very slow to warm up. To aid ice making culverts should be sealed when installed. Drainage is important, make sure no water builds up in or around the culvert and prevent the likelyhood of heaving. Our final consolation is the fact that there is some advantages to living in the cold northern latitudes.

LITERATURE CITED

Lawrence, Tomas W. 1980. Eight Foot Diameter Squash Culvert For Seedling Tree Storage. Pamphlet. 10p. No publication data given.

Effects of Ethylene on Development and Field Performance of Loblolly Pine Seedlings[1]

James P. Barnett, Jon D. Johnson,
and Nancy J. Stumpff[2]

Abstract.--Ethylene, a plant growth regulator, was produced by loblolly pine (Pinus taeda L.) seedlings in cold storage. Production was cyclic, with a peak occurring that seemed associated with seedling dormancy. Higher than naturally occurring levels of ethylene stimulated root growth potential, bud activity, survival, and growth. However, the intermediate concentrations that were measured in the cyclic peaks had an inhibiting effect on seedling development and performance. Further research is needed to assess the economical significance of these cyclic concentrations on survival and growth.

INTRODUCTION

Ethylene has long been recognized as a naturally-occurring plant growth regulator that is implicated in a number of important physiological processes (Abeles 1973, Galston and Davies 1970). In amounts as low as a few hundred parts per billion, ethylene can inhibit root growth and bud development and reduce seedling vigor (Kramer and Kozlowski 1979, Wareing and Phillips 1973). Stimulation of ethylene production results from mechanical injury such as occurs during lifting of seedlings from nursery beds (Yang and Pratt 1978).

Few of the effects of ethylene on tree seedlings are known, although this subject has received considerable attention in recent years. Barnett (1981) reported a 75 percent increase in root growth potential of loblolly pine (Pinus taeda L.) seedlings stored for 6 weeks in the presence of an ethylene absorbent. Terminal growth of Fraser fir (Abies fraseri (Pursh) Poir.) seedlings was reduced by 22 percent by exposure to 17.5 ppm of ethylene for 8 weeks in cold storage (Hinesley and Saltveit 1980). Graham and Linderman (1981) found that lateral root growth of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seedlings was inhibited at ethylene concentrations greater than 150 ppb.

This paper summarizes a series of studies that have evaluated the physiology of ethylene production in loblolly pine seedlings and the effects of ethylene on seedling development and field performance.

METHODOLOGY

The research with loblolly pine by Barnett (1981) was the stimulus for the later series of studies. In this early work with an ethylene absorbent (Purafil ES®)[3] that improved root growth potential and field seedling survival, three replications of seedlings were stored for 3 and 6 weeks in polyethylene bags with and without packets of the absorbent. In response to the positive results from this work, a cooperative effort began with Dr. Jon Johnson of Virginia Polytechnic Institute and State University. In the first of the studies reported by Johnson

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[1] Paper presented at the Intermountain Nurserymen's Association Meeting, Fort Collins, CO, August 13-15, 1985.

[2] Principal Silviculturist, USDA-Forest Service, Alexandria Forestry Center, Pineville, LA; Assistant Professor, Department of Forestry, University of Florida, Gainsville, FL; and Laboratory Technician, Savannah River Ecology Laboratory, Aiken, SC. Johnson and Stumpff were at the Department of Forestry, Virginia Polytechnic Institute, Blacksburg, VA, when the research was conducted.

[3] The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute offical endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

(1983), the atmospheres of two cold storage facilities for seedlings were sampled over a 3-month period during the winter of 1981-82 to determine the extent of ethylene accumulation. Depending upon the location of the facility, biweekly or monthly samples using Vacu-Samplers® were replicated 2 or 4 times. Some sampling of ethylene levels in kraft-polyethylene (K-P) seedling storage bags was also done. The samples were analyzed on a Bendix 2500® gas chromatograph. Complete details of the analysis techniques have been reported (Johnson 1983).

Studies to evaluate the dose-response relationship between ethylene and the performance of loblolly pine seedlings were then conducted. Seedlings lifted late in the season (March) were sealed in K-P bags and exposed to one of six treatments: control, 500 ppb, 1,000 ppb, 2,000 ppb, and 4,000 ppb of ethylene. An additional treatment involved placing a packet of Purafil in the bag with the seedlings. Ethylene concentrations were monitored periodically with gas chromatography, and the concentrations were adjusted as required. The seedlings were stored at 4°C for 6 weeks and then were measured for root growth potential and survival (Johnson and Stumpff 1984b) and for bud activity and first-year heights (Johnson and Stumpff 1984a). The methodology for the estimation of stage of bud development was reported by Johnson and Barnett (1984).

In addition to the evaluation of dose-response relationships, tests were also conducted to determine the effects of lifting date on ethylene production, identify whether ethylene originated in the roots or shoots, and compare the effect of machine versus hand lifting on subsequent ethylene production. Loblolly pine seedlings were lifted monthly from early to late in the season (November to March). Whole seedlings or roots and shoots individually were packaged in K-P bags for 1 week at 3°C. The ethylene concentration within the bags was measured using gas chromatography (Johnson and Stumpff 1985, Stumpff 1984).

RESULTS AND DISCUSSION

Barnett's (1983) data indicated that the presence of an ethylene absorbent greatly increased root growth potential and improved field seedling survival by 6 percentage points, even after three growing seasons (Table 1). No direct measurements of ethylene production were made, but the data suggest that ethylene is produced by loblolly pine seedlings and that it may be, at least partially, responsible for rapid deterioration of seedlings in storage.

Accumulation in cold storage

Johnson (1983) then evaluated the ethylene concentrations in two cold storage facilities and in a limited number of seedling bales and K-P bags. In the storage facility that handled open seedling bales, ethylene concentrations reached

Table 1.--Root growth potential, survival, and heights of loblolly pine seedlings lifted from nursery beds and stored in polyethylene bags with and without Purafil ES[1] media (from Barnett 1983)

		Stored 3 weeks			Stored 6 weeks		
Treatment	Application	RGP[2]	Survival	Height	RGP[2]	Survival	Height
		No.of new roots	%	Ft	No.of new roots	%	Ft
Without Purafil ES	1	163	92	5.4	80	84	4.8
	2	133	76	4.8	90	80	4.3
	3	120	88	4.5	84	84	4.9
Average[3]		139a	85b	4.8 a	85b	83b	4.7a
With Purafil ES media	1	125	92	4.8	158	88	5.2
	2	106	92	4.3	143	88	4.8
	3	159	88	5.2	147	92	4.5
Average[3]		130a	91a	4.8a	149a	89a	4.9a

[1] Purafil ES is the trade name of the ethylene absorbent.

[2] RGP = root growth potential, which is the number of new roots per seedling after 1 month under controlled conditions.

[3] Means within columns followed by the same letter are not significantly different at the 0.05 probability level for RGP and at the 0.10 probability level for field measurements. Survival and heights reported are those measured after 3 years in the field.

physiologically significant levels (2,300 ppb) in late December (fig. 1). The levels dropped rapidly after this peak was reached, which may have been related to chilling hours or seedling dormancy. Gasoline-powered forklifts were used in this facility and may have added to the ethylene in the atmosphere, but this could not explain the sharp peak in the facility that handled seedling bales. At the other facility, ethylene concentrations remained virtually constant at, or slightly above, the control concentration of 200 ppb. This lack of change was attributed to the use of sealed K-P bags for seedling packaging. Gas samples from within seedling bales and K-P bags indicated that loblolly pine seedlings do produce ethylene.

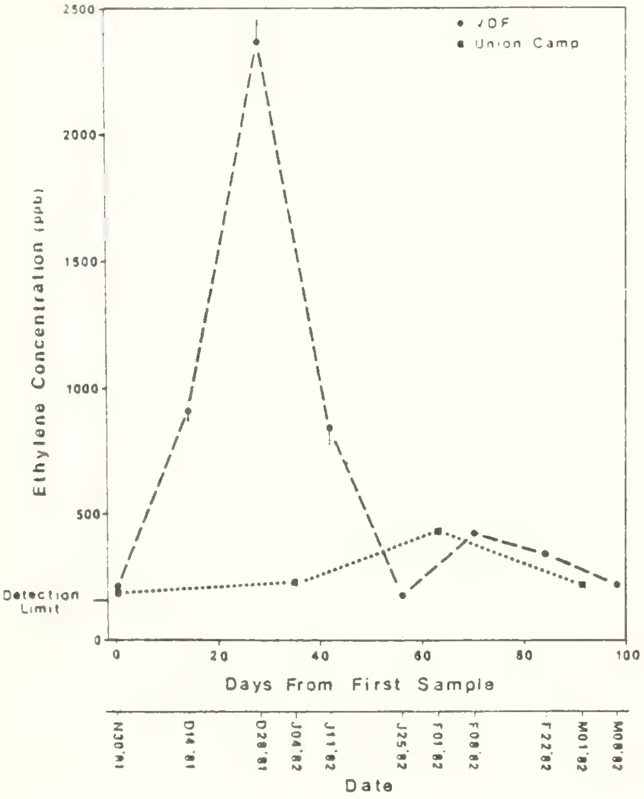

Figure 1.--Ethylene concentration in cold storage facilities of Virginia Division of Forestry and Union Camp during the 1981-82 season. Standard errors are represented by vertical lines where they are larger than the symbols (from Johnson 1983)

Lifting date and method

Evaluations of seedlings lifted monthly from November to March in the following year (1983) and packaged whole or separated into roots or shoots indicated that ethylene production is cyclic, with a maximum concentration occurring in February, perhaps when the chilling hours were met (Johnson and Stumpff 1985). The roots and shoots produced similar quantities of ethylene, about 0.10 ppb/g, except in February when the roots produced about twice as much as the shoots (fig. 2). The significance of this burst of ethylene production is unknown, but it may be associated with the dormancy process. Corroborative data for the involvement of ethylene in bud dormancy comes from a separate study in which bud break was assessed monthly (Johnson and Barnett 1984). In that test, the chilling requirement for bud break was not met until after February 1, 1983. The ethylene peak may correspond with a shift in seedling metabolism from a dormant state of activity in preparation for bud break.

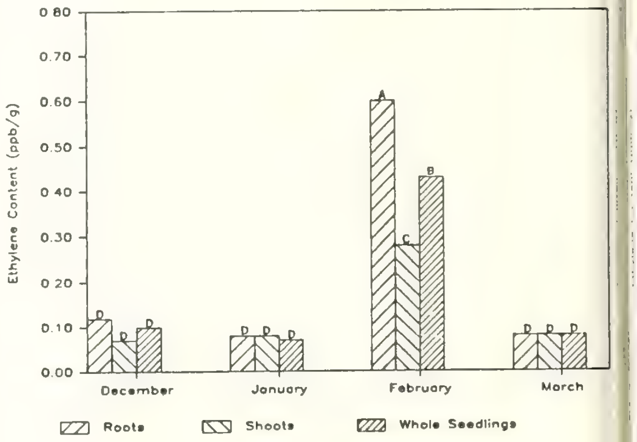

Figure 2.--Ethylene content of K-P bags containin whole seedlings, roots, and shoots of loblolly pine lifted monthly from December t March. Bars with the same letter are not statistically different at the 5 percent probability level (from Johnson and Stumpff 1985)

Lifting method had a significant effect on ethylene production (Johnson and Stumpff 1985). The amount of ethylene produced remained constant for hand lifting between January and March (fig. 3). As a result of machine lifting, however, ethylene content increased from 38 percent in January to 263 percent in March. Machine lifting not only tended to break roots, but the stems of some were compressed by the belts of the lifting machine. The differences in the amounts of ethylene produced between different lifting dates may reflect the change in dormancy status of the seedlings.

Dosage-rate evaluations

Loblolly seedlings lifted in March were exposed to six ethylene treatments (a control, an ethylene absorbent (Purafil ES), and 500, 1,000, 2,000, and 4,000 ppb of ethylene) and stored for weeks before outplanting. The seedlings were evauated for root growth potential, field bud activity, survival, and first-year height growth.

Root growth potential, measured both as cumulative length of new roots and total number of new roots, was significantly affected by ethylene fumigation. The 4,000-ppb and 500-ppb treatments resulted in the greatest root growth potential (Johnson and Stumpff 1984b). The Purafil and control treatments were intermediate, while the 1,000-ppb and 2,000-ppb treatments consistently had the lowest root growth potential.

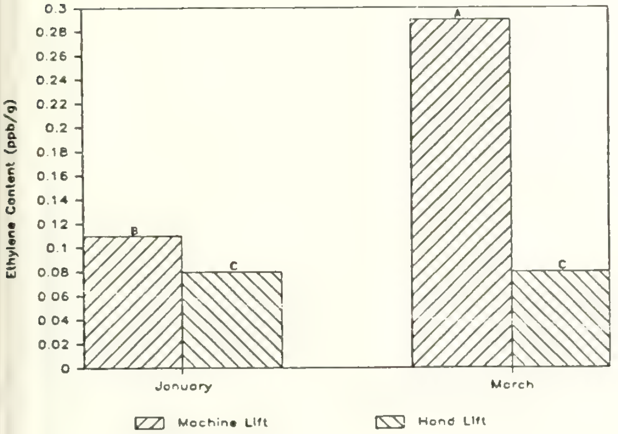

Figure 3.--The effect of lifting method, machine vs. hand, on ethylene content in K-P bags of loblolly pine seedlings lifted in January and March. Bars with the same letter are not statistically different at the 5 percent probability level (from Johnson and Stumpff 1985).

Bud activity assessed 1 month after outplanting by the method of Johnson and Barnett (1984) was significantly affected by the ethylene treatments (Fig. 4). The 4,000-ppb treatment stimulated bud break, but the responses to the other treatments were essentially the same. Spring bud activity as measured here is probably a reflection of root growth; seedlings that initiate early root growth also break bud sooner (Johnson and Barnett 1984, Johnson and Stumpff 1984b). The 4,000-ppb treatment had a positive effect on both root growth and bud break. Zaerr and Lavender (1980) reported a similar response in early-lifted Douglas-fir seedlings exposed to 5,000 ppb of ethylene during 1 month of storage.

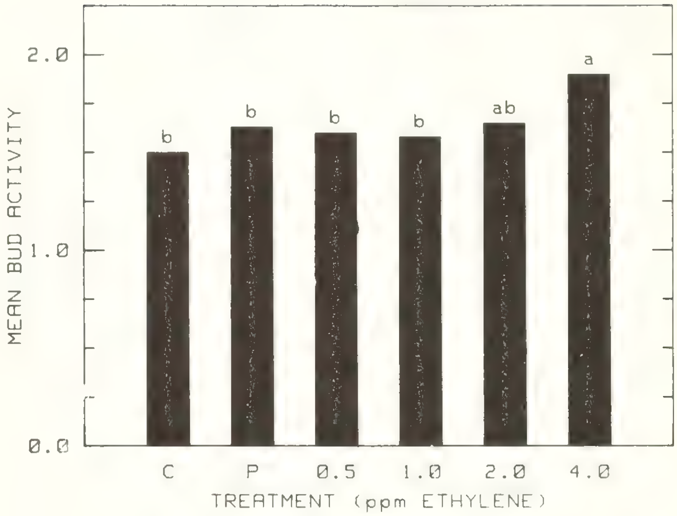

Figure 4.--Mean bud activity 1 month after outplanting of loblolly pine seedlings stored for 6 weeks. Storage treatments were: C - control; P - Purafil; 0.5, 1.0, 2.0, 4.0 - ethylene concentration in parts per million injected and maintained in seedling K-P bags. Bars with the same lower case letter are not statistically different at the 5 percent probability level (from Johnson and Stumpff 1984b). (Explanation of mean bud activity is given in Johnson and Barnett 1984.)

Survival after 1 year in the field was high, ranging from 94 to 99 percent (Fig. 5). Seedlings fumigated with 4,000 ppb of ethylene averaged 99 percent survival, which was higher than all other treatments except the Purafil treatment. The lowest survival was in the 1,000-ppb treatment, which appears to be in the range of concentration measured in the cold storage facilities. However, survival for all treatments was so great that there were no practical differences.

Seedling heights after 1 year in the field were affected by treatment and, again, the 4,000-ppb treatment promoted the greatest response (Fig. 6). All the other ethylene fumigation treatments resulted in similar heights, while the control and Purafil treatments resulted in lower heights.

The results of these studies illustrate that ethylene is physiologically active in loblolly pine seedlings. The responses may be inhibiting or stimulatory, depending upon the dosage to which particular seedling tissue is exposed.

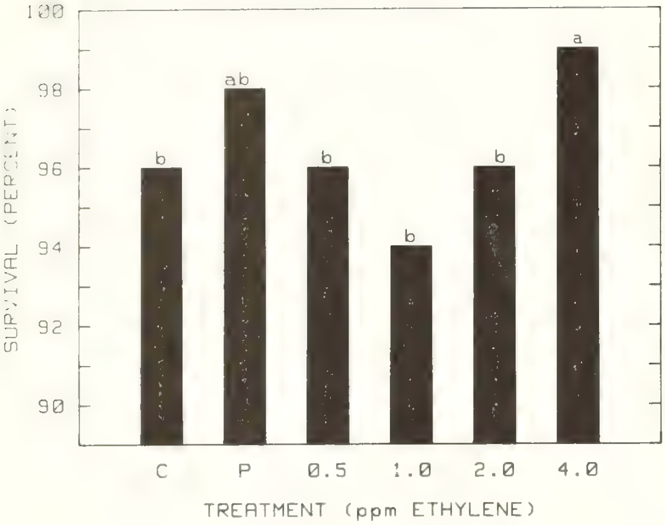

Figure 5.--Survival of loblolly pine seedlings stored 6 weeks after 1 year in the field. (Treatments and statistics are described in figure 4.)

CONCLUSIONS

These results appear to be, at first, conflicting. Ethylene at the 4,000-ppb rate stimulated root growth potential, bud development, survival, and height growth. However, lower concentrations inhibited at least some seedling physiological responses. Abeles (1973) has documented a wide scope of research with other types of plants that demonstrate that ethylene may be inhibiting or stimulating, depending upon concentration.

It is important to note that the 4,000 ppb of ethylene that resulted in positive physiological responses was higher than any level measured under natural conditions in either seedling storage facilities or bags. The 4,000-ppb concentration was also difficult to maintain. Ethylene is a very elusive gas and could not be maintained in sealed K-P bags without repeated fumigation.

Production of ethylene is cyclic, seemingly dependent upon the physiological state of the seedlings. The peaks of production seem closely related to some phase of seedling dormancy. These results must be viewed as an initial attempt to demonstrate the effects of ethylene on seedling survival and growth. Although a reduction in seedling survival due to exposures to ethylene wa determined, its overall effect on the performance of loblolly pine seedlings is probably not major. The most practical approach to reducing ethylene concentrations that could affect seedling performance would be to install ethylene-absorbent scrubbers in cold-storage facilities where problems may exist. Further research is needed t assess the economical significance of these cycli concentrations of ethylene on seedling performance.

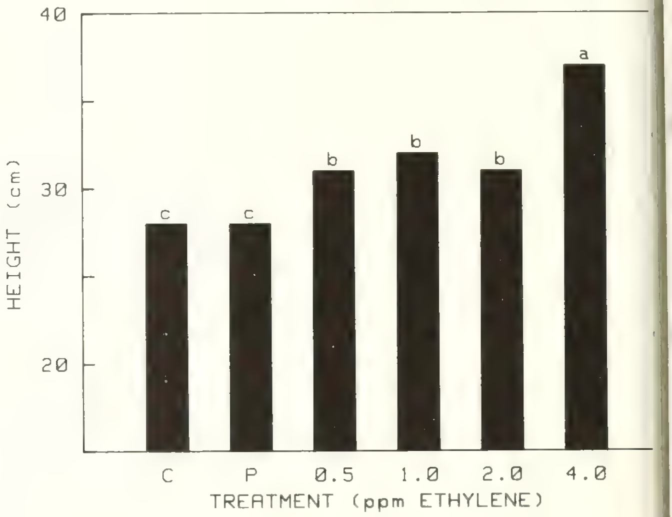

Figure 6.--Heights of loblolly pine seedlings stored 6 weeks after 1 year in the field. (Treatments and statistics are described in figure 4.)

LITERATURE CITED

Abeles, F. B. Ethylene in plant biology. New York, NY: Academic Press; 1973. 302 p.

Barnett, James P. Ethylene absorbent increases storability of loblolly pine seedlings. In: Proceedings, 1980 Southern Nursery Conference; 1980 September 2-4; Lake Barkley, KY; Atlanta, GA: FS Technical Publication SA-TP17. Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1981: 86-88.

Barnett, James P. Ethylene: a problem in seedling storage? Tree Planters' Notes 34(1): 28-29; 1983.

Galston, A. W.; Davies, P. J. Control mechanisms in plant development. New Jersey. Prentice-Hall; 1970. 184 p.

Graham, J. H.; Linderman, R. G.. Effect of ethylene on root growth, ectomycorrhizae formation and *Fusarium* infection of Douglas-fir. Canadian Journal of Botany 59: 149-155; 1981.

Hinesley, L. E.; Saltveit, M. E. Ethylene adversely affects Fraser fir planting stock in cold storage. Southern Journal of Applied Forestry 4: 188-189; 1980.

Johnson, Jon D. Ethylene accumulation during cold storage of pine seedlings: Is it a problem? In: Proceedings, 1982 Southern Nursery Conferences; 1982 July 12-15; Savannah, GA; 1982 August 9-12; Oklahoma City, OK; Atlanta, GA: FS Technical Publication R8-TP4. Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1983: 224-228.

Johnson, Jon D.; Barnett, James P. Loblolly pine seedling vigor based on bud development. In: Proceedings, 1984 Southern Nursery Conferences; 1984 June 11-14; Alexandria, LA; 1984 July 24-27; Asheville, NC; Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1984: 138-144.

Johnson, Jon D.; Stumpff, Nancy J. Loblolly pine seedling performance is affected by ethylene. In: Proceedings, 1984 Southern Nursery Conferences; 1984 June 11-14; Alexandria, LA; 1984 July 24-27; Asheville, NC; Atlanta, GA: U.S. Department of Agriculture, Forest Service; 1984a: 169-173.

Johnson, Jon D.; Stumpff, Nancy J. The influence of ethylene on root growth capacity and field performance. In: Proceedings, Eighth North American Forest Biology Workshop; 1984 July 30-August 1; Logan, UT. Logan, UT: Utah State University; 1984b: 190.

Johnson, Jon D.; Stumpff, Nancy J. Loblolly pine seedling ethylene production as affected by lifting time and method. In: Proceedings Third Biennial Southern Silvicultural Research Conference; 1984 November 7-8; Atlanta, GA. General Technical Report SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service; 1985: 34-37.

Kramer, P. J.; Kozlowski, T. T. Physiology of woody plants. New York, NY: Academic Press; 1979. 811 p.

Stumpff, Nancy J. Ethylene production by loblolly pine seedlings during cold storage and water stress. Blacksburg, VA: Virginia Polytechnic Institute and State University; 1984. 156 p. Thesis.

Wareing, P. F.; Phillips, I.D.J. The control of growth and differentiation in plants. New York, NY: Pergamon Press; 1973. 303 p.

Yang, S. F.; Pratt, H. K. The physiology of ethylene in wounded plant tissues. In: Kadl, G., ed. Biochemistry of wounded plant tissues. New York, NY: Walter de Grayter and Co.; 1978: 595-622.

Zaerr, J. B.; Lavender, D. P. Analysis of plant growth substances in relation to seedling and plant growth. New Zealand Journal of Forest Science 10: 186-195; 1980.

Herbicides for Weed Control in Tree Nurseries[1]

Lyle K. Alspach[2]

Abstract.--Weed control during tree seedling production is of major importance. The Tree Nursery at Indian Head, Saskatchewan, Canada is currently using and testing herbicides to supplement the weed control program. Current uses include: chloroxuron for caragana sowings; chloroxuron or linuron for poplar and willow cuttings; trifluralin for Siberian elm sowings; linuron for choke cherry sowings, conifer transplants and all 1-0 deciduous crops. Promising treatments for future use include: EPTC for caragana sowings, chloramben for honeysuckle sowings, oxyfluorfen for poplar and willow cuttings and conifer sowings and linuron for green ash sowings.

INTRODUCTION

The PFRA Tree Nursery at Indian Head, Saskatchewan, Canada annually produces six to seven million deciduous and coniferous bare root seedlings for distribution to over ten thousand applicants. These seedlings are utilized in field, farm and roadside shelterbelts as well as wildlife and municipal plantings where they reduce wind erosion, provide snow control, food and shelter for wildlife and add aesthetic value.

Good weed control is a major part of seedling production and requires the use of herbicides in addition to the usual manual and mechanical weed control operations. Over the past 25 years the Tree Nursery at Indian Head has been involved in investigative work to establish herbicide practices which can be incorporated into production of bare root tree seedlings.

Major nursery crops at Indian Head include: caragana (Caragana arborescens), green ash (Fraxinus pennsylvanica lanceolata), willow (Salix spp.), poplar (Populus spp.), villosa lilac (Syringa villosa), Manitoba maple (Acer negundo), Siberian elm (Ulmus pumila), choke cherry (Prunus virginiana melanocarpa), buffaloberry (Shepherdia argentea), Colorado spruce (Picea pungens), white spruce (Picea glauca), and Scots pine (Pinus sylvestris).

Herbicides are used during the first year of production for all of the nursery crops listed except green ash, villosa lilac, Manitoba maple and buffaloberry. Work is ongoing for green ash, villosa lilac and honeysuckle (Lonicera tatarica) with additional work to evaluate new chemicals for caragana, poplar, willow, and conifers.

Herbicide Treatments Currently Used in Seedling Production

Immediately after sowing caragana, chloroxur (Tenoran 50 WP) is applied at 5.6 kg/ha. Overhead irrigation provides incorporation. This treatment has generally provided satisfactory results, however, organic matter content of the soil would appear to be a limiting factor as indicated in a 1979 study in which poor control occurred where organic matter content was 5.0 percent and good control was achieved in areas where the soil contained 3.0 percent organic matter. Increased rates of chloroxuron were tested in an attempt to overcome the decreased herbicidal affect caused by adsorption to soils containing higher levels of organic matter. Weed control at 10.0 kg/ha was not significantly better than 6.0 kg/ha, therefore the 6.0 kg/ha rate was retained. Chloroxuron application has no adverse affect on caragana and, in some instances, has actually resulted in increased growth.

Chloroxuron or linuron (Lorox L 48%F or Afolan F 45%F) are used during the production of rooted poplar and willow hardwood cuttings. Investigative trials indicated that linuron at 2.2 kg/ha or chloroxuron at 5.6 kg/ha could be safely applied after planting but before bud break. Even though initial testing was conducted using clones of northwest poplar (Populus jackii 'Northwest'), Walker poplar (Populus x deltoides 'Walker'), acute willow (Salix acutifolia) and laurel willow (Salix pentandra) more recent testing has indicated Walker poplar may be adversely affected by linuron application. If these results are confirmed, chloroxuron will be substituted for linuron for Walker poplar production. It should e noted that application of either linuron or hloroxuron should be followed by overhead rrigation to provide soil incorporation.

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[1] Paper presented at the Intermountain Nurseryman's Meeting (Colorado Sate University, Fort Collins, August 13-14, 1985).

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Many undesirable characteristics of Siberian lm have caused the Tree Nursery to drastically educe production of this species. In fields used o produce this crop, trifluralin is applied at .1 kg/ha and incorporated to a depth of 7 to 10 m seven days before sowing. Occasionally this rifluralin treatment has been observed to cause ome reduction in Siberian elm top growth. This eduction is not of concern as it improves the top o root ratio and the elm are still of sufficient ize at harvest time.

The Tree Nursery produces approximately 00,000 choke cherry per year. Linuron is applied t 1.7 kg/ha in late fall after the choke cherry re sown. Precipitation during the fall and winter rovide incorporation of the herbicide. This inuron treatment progressed through the Tree ursery's testing program without complication and fter three years, refinement of rate and pplication timing were established. The treatment as been included in Nursery production practices or a number of years and has not caused any dverse affects on choke cherry sowings.

Bare root conifer production at Indian Head nvolves a two year period of seedbed growth ollowed by two years growth in the transplant rea: three years for Colorado spruce. Considerable work has been conducted in an attempt to find n acceptable herbicide that can be applied reemergence for weed control in seedbeds of olorado spruce, white spruce and Scots pine. The ost promising herbicide tested, which is nfortunately no longer available, was fluorodifen (Preforan) a Ciba-Geigy product. Other promising erbicides tested included: napropamide (Devrinol), ifenox (Modown) and oxyfluorfen (Goal). The one hich is currently of interest and still being ested is oxyfluorfen. Its application has esulted in some injury to conifer seedlings, owever a reduction in rates of herbicide pplication may provide the desired margin of afety. A rate of 0.5 kg/ha is currently being ested.

In the conifer transplant area weed control is provided by linuron application at 2.2 kg/ha after transplanting and at 1.5 kg/ha applied each fall thereafter. Linuron application has not resulted in a residual buildup nor has it been found to have moved beyond a depth of 5.0 cm in the clay loam soil.

All deciduous species which require more than one growing season to produce receive a Linuron application at 1.7 kg/ha in the fall of the first year, once the abscission layer has formed. This treatment is particularly effective for control of winter annuals such as flixweed (Descurainia sophia), stinkweed (Thlaspi arvense) and shepherd's-purse (Capsella bursa-pastoris).

Herbicide Treatments Currently Being Tested for Use in Seedling Production

Several herbicides are presently being tested. Alternate treatments for weed control in caragana sowings include: EPTC (Eptam 80% EC), applied and incorporated prior to sowing, and 2,4-DB (Cobutox 40% EC), applied overall when caragana are in the first to fourth trifoliate leaf stage.

Results for the EPTC treatments have been very promising with no significant reduction in the stand or growth of caragana (table 1). At a rate of 4.0 kg/ha, EPTC has consistently provided excellent weed control.

Unfortunately, 2,4-DB has not provided the same kind of consistently promising results that EPTC has (table 2). A greenhouse trial in 1984 and a field study in 1985 resulted in 2,4-DB injury to caragana seedlings even though seedlings in 1982 and 1984 field studies did not show any such injury symptoms. Based on these results further evaluation is needed.

Linuron is currently being tested for use in green ash production. It has been tested in 1982 and 1983 and is scheduled for further testing in 1985. Test results to date indicate the most promising treatment is a fall application of 2.0-2.5 kg/ha applied after sowing (table 2).

Even though tatarian honeysuckle is a minor crop at the Tree Nursery some herbicide work has been conducted on this species Chloramben is the herbicide of interest and has shown considerable promise for preemergence use in honeysuckle sowings. In 1982, chloramben was applied preemergence to plots which had been sown to honeysuckle the previous fall and at 4.0 kg/ha provided fair weed control with no adverse affects on the honeysuckle (table 3). To further pursue this use of chloramben, rates of 4.0 to 6.0 kg/ha were applied in the fall of 1982, after sowing, and in the spring of 1983, before crop and weed emergence. All of the treatments except the 4.0 kg/ha rate, spring applied, provided good to excellent weed control, again without adverse affects on the honeysuckle. An additional study was conducted in 1984, testing rates of 4.0 to 7.0 kg/ha fall applied after sowing or spring applied prior to crop and weed emergence. All of the treatments provided good to excellent weed control with no adverse affects on stand or growth of honeysuckle.

Two factors have been taken into consideration during the planning of the current herbicide studies for poplar and willow cuttings. Firstly, inconsistent weed control with chloroxuron resulting from herbicide adsorption to soil organic matter and secondly, the possible negative effect of linuron application on the rooting and development of Walker poplar cuttings.

In a 1985 field study, the treatments of most interest involved oxyfluorfen at 0.5 and 1.0 kg/ha. Both rates provided satisfactory results for use in production of rooted poplar cuttings. For willow production, it appears rates exceeding

0.5 kg/ha may result in significantly reduced growth.

During grounds maintenance operations, at Indian Head, glyphosate (Roundup 36% SN) was applied to control unwanted brush of which lilac was a component. The lilac was not controlled indicating that the morphology of the lilac leaves and/or physiology of the lilac plants provided some degree of tolerance to glyphosate. In light of this it was decided to conduct a greenhouse screening study using low rates of glyphosate, applied at various leaf-stages. Initial rates tested were 1.0, 1.5 and 2.0 kg/ha applied when the villosa lilac seedlings were in the cotyledon, two and four leaf-stages. Results were very encouraging for all treatments except the 2.0 kg/ha rate, applied at the cotyledon stage, which reduced the stand and resulted in seedling injury.

Since the greenhouse screening in 1982 glyphosate has been tested on three occasions for villosa lilac sowings. The first time, rates of 1.0-2.5 kg/ha applied at the four to eight leaf-stage proved unsatisfactory. In 1983, rates of 0.50 and 0.75 kg/ha showed marginal acceptability: the seedlings recovered and achieved near normal growth in 1984.

In a study conducted in 1985, glyphosate at 0.25, 0.50 and 0.75 kg/ha alone and with the addition of concentrated sulfuric acid at 0.25% volume per volume was applied when villosa lilac were in the six to eight leaf-stage. Results indicate that a rate of 0.50 kg/ha with H_2SO_4 add will provide adequate weed control with some yellowing and stunting of villosa lilac seedlings (table 4). It is expected that these seedlings will recover and achieve normal growth in 1986.

CONCLUSION

As can be seen from the information reported herein, it takes at least three years, even if everything goes well, before a treatment can be considered for inclusion in a nursery's herbicide program. With the development and inclusion of each new herbicide treatment a nursery is able to increase the weed control options available, decrease labor requirements and reduce costs.

Table 1.--Stand, growth and weed control in caragana sowings as affected by EPTC application[1]

Treatment	Rate 1983	Rate 1984	Type of application	Stand 1983	Stand 1984	Growth[2] 1983	Growth[2] 1984	Weed[3] control 1983	Weed[3] control 1984
	(kg/ha)			(#/0.5m)	(#/2m)	(g)			
Check weeded	-	-		57	88	1.16	0.65	-	-
Check not weeded	-	-		100	72	1.89	0.52	0.0**	0.0**
EPTC	2.5	-		71	-	1.27	-	6.0	-
EPTC	3.0	3.0	Pre-sow	96	48	1.27	0.61	7.3	7.0
EPTC	3.5	3.5	incorporated	138	57	1.24	0.50	8.7	6.7
EPTC	4.0	4.0		82	69	1.28	0.48	8.8	8.6
EPTC	-	4.5		-	81	-	0.60	-	7.8

[1] Data based on means of three and four replications in 1983 and 1984, respectively.
[2] Growth: top dry weight per ten seedlings.
[3] Weed control: 0-no control, 9-complete control.
**Significantly less than for best weed control (P=0.01).

Table 2.--Stand, growth, seedling injury and weed control in fall sown green ash during 1983 as affected by linuron application[1]

Treatment	Rate	Time of application	Stand	Growth[2]	Seedling[3] injury	Weed[4] control
	(kg/ha)		(%)	(g)		
Check weeded	-		14	2.2	1.4	-
Check not weeded	-		17	2.2	2.7	0.0++
Linuron	1.5	Fall	16	2.5	3.1	6.1
Linuron	2.0		14	2.1	22.6	7.5
Linuron	2.5		16	2.1	19.2	7.8
Linuron	3.0		19	1.4	19.1	7.0
Linuron	1.5	Spring	19	1.8	13.4	2.3++
Linuron	2.0		12	1.9	26.8*	8.7
Linuron	2.5		13	1.7	26.6*	8.4
Linuron	3.0		14	1.4	53.9**	8.4

[1] Data based on means of four replications.
[2] Growth: top dry weight per seedling.
[3] Seedling injury: percent of seedlings with necrotic leaves.
[4] Weed control: 0-no control, 9-complete control.
*,**Significantly greater than for check weeded (P=0.05) and (P=0.01).
++Significantly less than for best weed control (P=0.01).

able 3.--Stand, growth and weed control in honeysuckle sowings as affected by preemergence chloramben application[1]

Treatment	Rate 1982	Rate 1983	Rate 1984	Time of application	Stand 1982	Stand 1983	Stand 1984	Growth[2] 1982	Growth[2] 1983	Growth[2] 1984	Weed control[3] 1982	Weed control[3] 1983	Weed control[3] 1984
	(kg/ha)				(#/.3m)	(#/.5m)	(#/.5m)		(g)				
heck weeded	-	-	-		47	83	19	1.7	1.0	10.8	-	-	-
heck not weeded	-	-	-		46	78	21	1.6	1.9	10.2	0.0**	0.0**	0.0**
hloramben	-	4.0	4.0	Fall after sowing	-	70	19	-	1.6	9.8	-	7.7	6.8
hloramben	-	5.0	5.0		-	85	24	-	1.4	8.9	-	7.5	7.5
hloramben	-	6.0	6.0		-	58	26	-	1.6	9.7	-	8.4	7.2
hloramben	-	-	7.0		-	-	27	-	-	10.1	-	-	7.8
hloramben	2.0	-	-	Spring prior to crop and weed emergence	45	-	-	1.9	-	-	2.5**	-	-
hloramben	3.0	-	-		44	-	-	1.7	-	-	4.7*	-	-
hloramben	4.0	4.0	4.0		53	71	17	1.5	1.6	12.6	6.1	5.0*	6.7
hloramben	-	5.0	5.0		-	87	23	-	1.5	13.2	-	6.7	7.6
hloramben	-	6.0	6.0		-	73	21	-	1.6	9.4	-	7.5	8.1
hloramben	-	-	7.0		-	-	24	-	-	10.9	-	-	7.9

[1] Data based on means of four replications.

[2] Growth: top fresh weight per seedling.

[3] Weed control: 0-no control, 9-complete control.

*,**Significantly less than for best weed control (P=0.05) and (P=0.01).

Table 4.--Preliminary results for seedling injury and weed control in villosa lilac sowings as affected by glyphosate application at the six to eight leaf stage[1]

Treatment	Rate	Seedling[2] injury	Weed[3] control
	(kg/ha)		
Check weeded	-	0.0	-
Check not weeded	-	0.0	0.0
Glyphosate	0.25	0.4	0.4
Glyphosate	0.50	3.3**	2.5
Glyphosate	0.75	3.9**	8.4
Glyphosate plus H_2SO_4	0.25 0.25% v/v	1.4**	0.7
Glyphosate plus H_2SO_4	0.50 0.25% v/v	3.2**	6.9
Glyphosate plus H_2SO_4	0.75 0.25% v/v	4.2**	8.1

[1] Data based on means of four replications.

[2] Seedling injury: 0-no yellowing, 9-severe yellowing.

[3] Weed control: 0-no control, 9-complete control.

**Significantly more than for check weeded (P=0.01).

Forest Tree Nursery Herbicide Studies in the Northern Great Plains: Herbicide Phytotoxicity Tables[1]

Lawrence P. Abrahamson[2]

Abstract.--Eight herbicides (registered for similar uses in the U.S.) were extensively evaluated at 15 forest tree nurseries in Western and Northern United States for weed control on first year seedling nursery beds. Phytotoxicity evaluations of dcpa, napropamide, oxyfluorfen, diphenamid, bifenox, oxadiazon, trifluralin and prometryn on 38 different conifer and hardwood species are presented.

Additional keywords: Enide®, Treflan®, Dacthal®, Caparol®, Devrinol®, Modown®, Goal®, and Ronstar®.

INTRODUCTION

The USDA Forest Service developed a number of nursery herbicide projects in the United States out of a recognition of the potential benefits of herbicidal control of weeds in nursery seedbeds. This paper will concentrate on projects conducted at 15 nurseries in the Great Plains, the Lake States and in New York. The forest tree nurseries were part of the following projects. The cooperative western nursery herbicide project, initiated in 1976, was with cooperation among state, private and federal nurseries, Forest Service Research, State and Private Forestry, National Forest Systems, and State University of New York out of Syracuse. Twenty-eight nurseries in 12 states were involved in this effort which was broken down into three segments, each of three-year duration; the Pacific Coast started in 1976 (Stewart 1977, Owston et al. 1980, Owston and Abrahamson 1984), the Intermountain-Great Basin in 1977 (Ryker and Abrahamson 1980), and the Great Plains in 1978 (Abrahamson 1981, Abrahamson and Burns 1979). In 1979 the Northeastern (NE) Area started an eastern nursery herbicide project in five states cooperating with Purdue University and State University of New York (SUNY) at Syracuse (Holt and Abrahamson 1980). In 1981 the NE Area expanded the eastern nursery herbicide project to the Great Lakes area with eight nurseries (state, federal and private) in three Lake States cooperating with SUNY (Abrahamson and Jares 1984). During 1982 Oklahoma State (Abrahamson 1983) also sponsored a nursery herbicide project of their own in cooper tion with SUNY to help the nursery expand on the herbicide studies using different herbicides, tr species and sowing times.

What is important in these projects is that all studies have similar objectives and methodol gies and that information developed from one reg n or study project is supportive of that from othe regions. In all these studies the objectives we to identify promising herbicides, develop data f product registration, and demonstrate safe and effective weed control practices for nursery see beds.

METHODS

The nursery herbicide screening and demonstration projects were initiated as part of a three-year study. During the first year of the three-year study up to ten herbicides (eight of which are represented in Table 1) were screened two to four major species of spring- and/or fall sown conifers and/or hardwoods depending on the nursery involved in the study.

Treatments were applied to three-foot long plots in four-foot wide nursery beds with a one-foot untreated buffer between plots. All treatments were installed in a randomized block desig with three replications per species. Herbicides were applied with a modified AZ plot pressurized sprayer equipped with check valves and four flat fan 8001 nozzles operated at 20 psi in a water carrier at a volume equivalent to 85 ppa (100 ml plot). Granular formulations were ocularly applied from a hand shaker uniformly over the plot.

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[1] Paper presented at the Intermountain Nurserymen's Association 1985 Annual Meeting. [University Park Holiday Inn, Fort Collins, August 13-15, 1985].

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Pre-seeding incorporated treatments were applied no more than one day before seeding and incorporated into the top two inches of soil using a garden rake. Post-seeding treatments (Ps) were applied within two days after seeding, except on the fall-sown species which were applied any time after fall seeding but before mulching. Post-germination treatments (Pg) were applied four to six weeks after seedling emergence, except on the fall-sown species which were applied in the spring after mulch was removed and seedlings had emerged.

Herbicidal damage to conifers/hardwoods at the end of the first growing season was evaluated using a ten-point rating scale (0 is complete kill, 10 is no effect) proposed by Anderson (1963). Height of nine randomly selected seedlings and number of seedlings per foot in three randomly selected rows in each plot were also measured to determine chemical effects on germination, seedling growth and survival.

The objectives of the second-year studies were to evaluate the phytotoxicity and weed control effectiveness of three to four herbicides screened from the first-year study to be non-phytotoxic to the species tested and have reasonable weed control of weeds present at that nursery. Phytotoxicity was evaluated by using herbicidal damage ratings (Anderson 1963), seedling survival (number/foot) and height growth (cm). Dosages of 1X, 2X, and 1X + 1X of these herbicides were applied post-seeding and/or post-germination using three-foot long plots in four-foot wide beds with a one-foot untreated buffer between plots. All treatments were installed using a randomized block design with three replications per species. Herbicide treatments were applied by small pressurized sprayer or hand shaker as was done the first year of these studies.

Weed control effectiveness of the best treatments selected from the second year study were evaluated the third year under operational use using nursery application equipment on 100-foot test plots. The herbicides were evaluated for weed control under operational use at the 1X rate of application applied post-seeding alone, or post-seeding and post-germination. Phytotoxicity rating, survival and height measurements were also recorded from these operational plots.

RESULTS AND DISCUSSION

Since each nursery is a study in itself, this paper will only concentrate on studies completed at 15 nurseries in the Great Plains, the Lake States and New York (Abrahamson 1984). Phytotoxicity data from these nurseries is presented in Tables 2-15, listed by herbicides tested under each species. The tables are summaries of all the phytotoxicity studies and indicate; 1) those fall- and/or spring-sown seedlings where the herbicide has been safely applied at rates indicated without stunting or germination reduction (x); 2) herbicides that appear to be promising at rates indicated, but because of possible phytotoxic problems implied in some of our studies, these should be thoroughly tested before using at your nursery (o); 3) herbicides that should not be used at rates indicated because of severe phytotoxic damage (-). One herbicide that should be elaborated on is napropamide. Napropamide is used at the lower rate (1.5 lbs ai per acre) when the nursery soil has below 1 percent organic matter, otherwise the higher rate (3.0 lbs ai per acre) is normally used. Napropamide is safe to use post-seeding on most spring-sown conifer species tested, but caused severe stunting when applied post-seeding to fall-sown conifer species in the Lake States study. Napropamide applied post-germination to both spring- and fall-sown conifers caused no phytotoxic problems.

Weed control expressed in terms of hand-weeding time, or "how much time can herbicides save you versus hand-weeding" is one of the most important aspects of these studies. In the Great Plains study (Abrahamson 1981) on spring-sown species the post-seeding applications were as effective as the post-seeding plus post-germination applications for total season weed control. The Norman Nursery in Oklahoma is an example (Abrahamson 1983) of the type of savings in time and money that can be expected from these herbicides when used in forest tree nurseries.

Hand weeding time at the Norman Nursery was reduced by an average of 80 percent for all herbicides applied only in the spring (Ps) while those applied in both the spring and a second application five to six weeks later (Ps + Pg) reduced hand weeding time by an average of 87 percent. Based on minimum wage of $3.35 per hour, this would amount to an average gross saving of $4,600 per acre of seedbed (without figuring in cost of herbicide or application costs) weeded six times with a mean weeding time of 283 man hours per acre untreated seedbeds at Norman (Abrahamson 1983).

SUMMARY

There have been numerous trials, studies and tests of various herbicides at many different nurseries that have demonstrated the safe and effective use of dcpa, napropamide, oxyfluorfen, diphenamid, bifenox, oxadiazon, trifluralin, and prometryn on various conifer and/or hardwood first year seedling nursery beds. These herbicides have reduced the time required to hand-weed nursery beds by 80-87 percent when applied at sowing time alone or with a second application four to six weeks later. Over $4,000-$7,000 per acre of seedbed could be saved by using these herbicides over hand-weeding alone.

However, the safety and effectiveness of any herbicide should be tested at each nursery before operational use. These herbicide trials are urged because there is a strong possibility of differential results from varied interactions of

Table 1. Herbicides, rates, and application timings used in the Nursery Herbicide Studies Conducted by SUNY.

				Application Timing[1]		
Herbicide	Formulation	Manufacturer	(lb ai/A)	Pre-Seeding Incorporation or Post-Seeding	Post-Germination	Post-Seeding Plus Post-Germination
Diphenamid	Enide 50W; 90W	Upjohn	4.0	x	x	x
Trifluralin	Treflan 4EC	Elanco	0.75	x	-	-
DCPA	Dacthal W-75	Diamond-Shamrock	10.5	x	x	x
Prometryn	Caparol 80W	Ciba-Geigy	1.0	x	x	x
Napropamide	Devrinol 50W	Stauffer	1.5/3.0	x	x	x
Bifenox	Modown 80W; 4F	Rhone-Poulenc	3.0	x	x	x
Oxyfluorfen	Goal 2E; 1.6E	Rohm & Haas	0.5	x	x	x
Oxadiazon	Ronstar G	Rhone-Poulenc	1.0	x	x	x
Napropamide & Bifenox	Tank mix		1.0+3.0	x	x	x

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[1] Pre-seeding incorporation: incorporated into top 2 inches of soil immediately before seeding.
Post-seeding: broadcast applied to soil immediately after seeding.
Post-germination: broadcast applied to soil 4 to 5 weeks after seedling emergence.
Post-seeding plus post-germination: two separate applications at the full recommended rate.

different mixtures of tree and weed species, soil and climatic factors, and cultural practices at different nurseries. If a particular herbicide has never been used at your nursery, several years of trials are advisable because of variations in effects caused by different weather conditions. Trials should include "double doses" to evaluate the safety limits on crop seedlings and leave an untreated control to properly evaluate the effects of the herbicide.

LITERATURE CITED

Abrahamson, L.P. 1981. Herbicide trials for weed control in Great Plains Forest tree nurseries. In: Proceedings of the 33rd Annual Meeting of the Forestry Committee, Great Plains Agr. Council, June 1981, Lubbock, TX, Great Plains Agr. Council Publ. #102; p. 65-102.

Abrahamson, L.P. 1983. Herbicides, an important component of the weed control program at Oklahoma State (Norman) Nursery. In: Proceedings of the 1982 Southern Nurserymen's Conf., Southern Region, U.S. Forest Service, Technical Publ. R8-TP4, p. 171-191.

Abrahamson, L.P. 1984. Forest tree nursery herbicide studies in the Northeastern United States: Highlights of research results. In: Proceedings of the Workshop: Weed Control in Tree Nurseries, July 17-18, 1984, PFRA Tree Nursery, Indian Head, Saskatchewan. Agriculture Canada, PFRA. p. 6-21.

Abrahamson, L.P. and K.F. Burns. 1979. Herbicide screening for weed control in western forest tree nurseries - Great Plains Segment. AFRI, Syracuse, NY, Res. Report No. 41; 15 pp.

Abrahamson, L.P. and T. Jares. 1984. Forest tree nursery herbicide studies in the Lake States and New York: Highlights of research results. In: Northeast Area Nursery Supervisors Conference Proceedings, August 6-9, 1984, Dover, Delaware, Sponsored by Delaware Forest Servic 25 pp.

Anderson, W.H. 1963. A system for evaluating effective weed control in forest nurseries. Tree Planter's Notes (Oct.):19-23.

Holt, H.A. and L.P. Abrahamson. 1980. Developing weed control programs for forest nurseries in central U.S. In: Abstracts - 1980 Meetin of Weed Sci. Soc. of Amer., Feb. 5-7, 1980, Toronto, Canada, p. 51.

Owston, P.W., R.E. Stewart, N.W. Callan, and L.P. Abrahamson. 1980. Evaluation of herbicides for weed control in Pacific Coast forest tree nurseries. In: Abstracts - 1980 Meeting of Weed Sci. Soc. of Amer., Feb. 5-7, 1980, Toronto, Canada, p. 51-52.

Owston, P.W. and L.P. Abrahamson. 1984. Weed management in forest nurseries. In: Duryea, M.L. and T.D. Landis (eds.), Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr. W. Junk Publishers. The Hague/Boston/Lancaster for Forest Research Laboratory, Oregon State Univ., Corvallis. 386 p. (p. 193-202).

Ryker, R.A. and L.P. Abrahamson. 1980. Western forest nursery herbicides study, Rocky Mountain-Great Basin Segment. In: Abstracts - 1980 Meeting of Weed Sci. Soc. of Amer., Feb. 5-7, 1980. Toronto, Canada, p. 52.

Stewart, R.E. 1977. Herbicides for weed control in western forest tree nurseries. Proceeding Western Society of Weed Science, 30:78-79.

TABLE 2: Phytotoxic effects of herbicides tested on first year ponderosa and lodgepole pine nursery beds.

Ponderosa Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*		x	x	x
trifluralin	*		x		
napropamide & bifenox	*		x	x	x

Lodgepole Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
trifluralin	*		o		
napropamide & bifenox	*		o	x	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 3: Phytotoxic effects of herbicides tested on first year loblolly and Austrian pine nursery beds.

Loblolly Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		o	x	o
trifluralin	*		x		
napropamide & bifenox	*		o	x	o

Austrian Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		o	x	o
diphenamid	*		x	x	x
bifenox	*		o	x	o
trifluralin	*		x		
napropamide & bifenox	*		o	x	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 4: Phytotoxic effects of herbicides tested on first year white and Scotch pine nursery beds.

White Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*	*	x	x	x
napropamide	*		x	x	x
napropamide		*	-	x	-
oxyfluorfen	*	*	x	x	x
diphenamid	*	*	x	x	x
bifenox	*	*	x	x	x
oxadiazon	*	*	x	x	x
trifluralin	*		x		
prometryn	*	*	x	x	x
napropamide & bifenox		*	o	x	o

Scotch Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*		x	x	x
trifluralin	*		x		
prometryn	*		x	x	x

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
\- = severe phytotoxic effects, Do Not Use.

TABLE 5: Phytotoxic effects of herbicides tested on first year red and jack pine, and Colorado blue spruce nursery beds.

Red and Jack Pine

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*	*	x	x	x
napropamide	*		x	x	x
napropamide		*	-	x	-
oxyfluorfen	*	*	x	x	x
diphenamid	*	*	x	x	x
bifenox	*	*	x	x	x
oxadiazon	*	*	x	x	x
prometryn	*	*	x	x	x
napropamide & bifenox	*		x	x	x
napropamide & bifenox		*	-	x	-

Colorado Blue Spruce

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		o	x	o
dcpa		*	x	x	x
napropamide	*		x	x	x
napropamide		*	o	x	o
oxyfluorfen	*	*	x	x	x
diphenamid	*		x	x	x
bifenox	*		o	x	o
bifenox		*	x	x	x
oxadiazon	*	*	x	x	x
trifluralin	*		x		
prometryn	*	*	x	x	x
napropamide & bifenox	*	*	o	x	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
\- = severe phytotoxic effects, Do Not Use.

TABLE 6: Phytotoxic effects of herbicides tested on first year white and Norway spruce nursery beds.

White Spruce

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*	*	x	x	x
napropamide	*		x	x	x
napropamide		*	o	x	o
oxyfluorfen	*	*	x	x	x
diphenamid	*	*	x	x	x
bifenox	*	*	x	x	x
oxadiazon	*		x	x	x
oxadiazon		*	o	x	o
trifluralin	*		x		
prometryn	*	*	x	x	x
napropamide & bifenox		*	x	x	x

Norway Spruce

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*		x	x	x
trifluralin	*		x		
prometryn	*		x	x	x

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 7: Phytotoxic effects of herbicides tested on first year Japanese larch, eastern red cedar, and white cedar nursery beds.

Japanese Larch

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	o	x	o
oxyfluorfen		*	x	x	x
diphenamid		*	x	x	x
bifenox		*	x	x	x
oxadiazon		*	x	x	x
trifluralin		*	x		
prometryn		*	x	x	x

Eastern Red Cedar

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	x	x	x
oxyfluorfen		*	x	x	x
diphenamid		*	x	x	x
bifenox		*	o	x	o
oxadiazon		*	x	x	x
trifluralin		*	x		
napropamide & bifenox		*	o	x	o

White Cedar

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	o	x	o
oxyfluorfen		*	-	x	-
diphenamid		*	x	x	x
bifenox		*	-	x	-
oxadiazon		*	x	x	x
trifluralin		*	x		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 8: Phytotoxic effects of herbicides tested on first year caragana, Russian olive, and black locust nursery beds.

Caragana

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		-	x	-
oxyfluorfen	*		-	x	-
diphenamid	*		x	x	x
bifenox	*		-	x	-
trifluralin	*		o		
napropamide & bifenox	*		-	x	-

Russian Olive

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		-	x	-
trifluralin	*		x		
napropamide & bifenox	*		-	x	-

Black Locust

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
napropamide	*		x	x	x
oxadiazon	*			x	
trifluralin	*		-		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 9: Phytotoxic effects of herbicides tested on first year hard and silver maple, and black walnut nursery beds.

Hard Maple

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	-	x	-
oxyfluorfen		*	o	-	-
diphenamid		*	x	x	x
bifenox		*	-	x	-
oxadiazon		*	-	x	-
trifluralin		*	o		
prometryn		*	x	-	-
napropamide & bifenox		*	-	x	-

Silver Maple

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		-	x	-
napropamide	*		o	x	o
oxyfluorfen	*		-		-
diphenamid	*		-	o	-
bifenox	*		-		-
oxadiazon	*			x	
napropamide & bifenox	*		-		-

Black Walnut

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	o	x	o
oxyfluorfen		*	x	o	o
diphenamid		*	x	x	x
bifenox		*	x	x	x
oxadiazon		*	x	x	x
trifluralin		*	x		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 10: Phytotoxic effects of herbicides tested on first year cotoneaster, Siberian elm, and honeysuckle nursery beds.

Cotoneaster

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	o	x	o
oxyfluorfen		*	o	-	-
diphenamid		*	x	x	x
bifenox		*	x	o	o
oxadiazon		*		x	
napropamide & bifenox		*	o	o	o

Lacebark Elm

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		o	x	
napropamide	*		-	x	-
oxyfluorfen	*		-		-
diphenamid	*		-	o	-
bifenox	*		-	-	-
oxadiazon	*			x	
trifluralin	*		o		
napropamide & bifenox	*		-		

Honeysuckle

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	-	-
napropamide		*	x	x	x
oxyfluorfen		*	o	-	-
diphenamid		*	o	o	o
bifenox		*	x	o	o
oxadiazon		*		-	-
trifluralin		*	x		
napropamide & bifenox		*	x	o	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 11: Phytotoxic effects of herbicides tested on first year white and green ash, and silky dogwood nursery beds.

White Ash

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	x	x	x
oxyfluorfen		*	x	-	-
bifenox		*	o	x	o
oxadiazon		*	-	x	-
trifluralin		*	x		
prometryn		*	x	-	-

Green Ash

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		-	x	-
trifluralin	*		x		
napropamide & bifenox	*		-	x	-

Silky Dogwood

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	-	-
napropamide		*	-	x	-
oxyfluorfen		*	-	-	-
diphenamid		*	x	x	x
bifenox		*	-	-	-
oxadiazon		*	-	-	-
trifluralin		*	x		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 12: Phytotoxic effects of herbicides tested on first year euonymus, hackberry, sycamore, and choke cherry nursery beds.

Euonymus

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*		x	
napropamide		*		x	
diphenamid		*		o	
oxadiazon		*		x	

Hackberry

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*		-	-
napropamide		*		x	
diphenamid		*	o	x	o
oxadiazon		*		x	

Sycamore

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		-	o	-
napropamide	*		o	o	o
oxyfluorfen	*		-		-
diphenamid	*		o	x	o
bifenox	*		-		-
oxadiazon	*			o	
napropamide & bifenox	*		-		-

Choke Cherry

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*		-	-
oxyfluorfen		*		-	-

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 13: Phytotoxic effects of herbicides tested on first year yellow birch, American plum, honeylocust, and lilac nursery beds.

Yellow Birch

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	-	-	-
napropamide		*	-	x	-
oxyfluorfen		*	-	-	-
diphenamid		*	x	x	x
bifenox		*	-	-	-
oxadiazon		*	-	-	-
trifluralin		*	-		
prometryn		*	x	-	-

American Plum

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*		o	
oxyfluorfen		*		o	

Honeylocust

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
oxyfluorfen	*			o	

Lilac

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
oxyfluorfen	*			-	-

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use
- = severe phytotoxic effects, Do Not Use.

TABLE 14: Phytotoxic effects of herbicides tested on first year redbud and catalpa nursery beds.

Redbud

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
napropamide	*		-	x	-
diphenamid	*			o	
oxadiazon	*			x	
trifluralin	*		o		

Catalpa

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			x	
napropamide	*		x	x	x
diphenamid	*			x	
oxadiazon	*			x	
trifluralin	*		-		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use
- = severe phytotoxic effects, Do Not Use.

TABLE 15: Phytotoxic effects of herbicides tested on first year poplar and willow cutting nursery beds.

Poplar Cuttings

Herbicide	Spring Plant	Fall Plant	Post-Plant	Post-Sprouting	Post-Plant & Sprouting
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	o	o
diphenamid	*		x	x	x
bifenox	*		x	o	o

Willow Cuttings

Herbicide	Spring Plant	Fall Plant	Post-Plant	Post-Sprouting	Post-Plant & Sprouting
dcpa	*		x	x	x
napropamide	*		o	x	o
oxyfluorfen	*		x	o	o
diphenamid	*		x	x	x
bifenox	*		x	o	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested, requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

Herbicides for Conifers: What's New[1]

Robyn L. Darbyshire[2]

Abstract.--Of recent interest to conifer nurserymen are the preemergence grass herbicides, with Poast (sethoxydim) and Fusilade (fluazifop-butyl) currently registered for use on conifers. Information about these herbicides and herbicides for yellow nutsedge control is discussed. Split applications, applications with low carrier volumes, and a new publication on backpack sprayers are also mentioned.

CHEMICALS

Postemergence Grass Herbicides

Introduction

The so-called "new grass killers" are currently receiving a lot of interest. They are not so new anymore, and are more commonly referred to as postemergence grass killers. Poast (sethoxydim) and Fusilade (fluazifop-butyl) are currently registered for use on non-bearing crops, including conifers. Another herbicide in this group is Verdict (haloxyfop-methyl--also known as Dowco 453). Verdict is not yet registered for use on conifers, but probably will be registered for this use in the future. Other graminicides you may have heard of include Assure, Hoelon, and Whip. These herbicides are active at fairly low rates (less than 0.5 pound active ingredient per acre), and kill both aboveground and belowground parts of the plant after being translocated to root and shoot meristems. They exhibit varying degrees of soil activity, with Fusilade having one of the shortest periods of soil activity (less than one month) and Verdict having one of the longest (up to one year). Newer versions of these graminicides will probably have even greater soil activity and persistence. Most of the information that follows on these herbicides will concern Poast and Fusilade.

Selectivity

Even though these herbicides are grouped together, they each exhibit a different chemistry and selectivity. To decide which of these herbicides to apply, you need to know the grass species that you are trying to control. Recent work in western Oregon has shown that certain herbicides are more effective against certain grass species (Brewster, 1984). For example, Verdict was more active against annual bluegrass than Poast or Fusilade, and Poast and Verdict control Italian ryegrass better than Fusilade. Fusilade however, is best for control of quackgrass. In general, Verdict is the most active herbicide of the three on young (4-5 leaf or 1-2 tiller stages) grasses. Some other work has shown however, that Poast may be more active on older grasses than Fusilade (Whitson, et al, 1985). None of these herbicides are effective against broadleaf weeds, rattail fescue or the fine fescues, and control of perennial grasses may take more than one application to get the desired result.

Additives

In applying these chemicals, READ THE LABEL CAREFULLY. The recommendations for crop oils and surfactants vary, depending on the chemical and the crop species. These additives are needed to increase plant uptake of the herbicides, especially under adverse conditions. Some of the crop phytotoxicity attributed to these herbicides, particularly when applied under warm and humid conditions, is thought to be due to the crop oils. If you suspect a problem, try treating a small area without the use of crop oil, another small area with the additive alone, and a third area with the herbicide plus the additive. The grass control will not be as good, but you may be able to determine if the additive is causing the phytotoxic effect. For further information on testing herbicides in nurseries, consult Sandquist, Owston, and McDonald (1981).

Mode of Action

These herbicides are translocated to the grass meristems within one to two hours of application, but obvious visual symptoms do not appear for at least two weeks. A few days after application however, the newest leaf should detach easily, and a longitudinal section of the stem should show discolored meristematic tissue at the newest node. As with most herbicide applications, these herbicides are most effective on smaller grasses. It is also important that the grasses be actively growing and unstressed by moisture, mowing, or other herbicide treatments, as these chemicals are translocated within the plant and require an intact plant to be most effective.

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[1] Paper presented at the 1985 Intermountain Nurseryman's Association Meeting. [Fort Collins, Colorado, August 13-15, 1985].

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Crop Phytotoxicity

Reported problems with these chemicals inlude possible phytotoxicity due to the crop oil. Use of these graminicides prior to the application of a broadleaf herbicide in some horticultural crops has resulted in damage to the crop due to greater uptake of the broadleaf herbicide by the crop. Tank mixes with broadleaf herbicides in horticultural crops have shown reduced activity, possibly due to reduced herbicide uptake (William, 1984).

Yellow Nutsedge Control

Yellow nutsedge is a weed of increasing importance. Recent work by Pereira (1985) has concentrated on the control of tuberization rather than control of top growth. If glyphosate is used to control this weed, it should be applied earlier than previously thought for greater control of tuberization. Another herbicide for nutsedge control is Dual (metolachlor). Two or more years of Dual applications were found to give good control in fruit orchards. If a serious infestation is present, you may need to rotate into a crop for which Dual is registered (corn, beans, some ornamentals) to eliminate the nutsedge.

Oregon State University
Nursery Technology Cooperative (NTC)

The Nursery Technology Cooperative (NTC) began screening experimental herbicides for bareroot nurseries in May 1984. The screening program has five phases, each with its own objective:

I. International Plant Protection Center (IPPC) Multicrop Screening Program
Objective: To provide phytotoxicity information on experimental chemicals and to aid the selection of promising chemicals for further screening.
II. Greenhouse Screening
Objective: To obtain more information on phytotoxicity and timing of application for chemical weed control methods.
III. First-Level Nursery Screening
Objective: To evaluate new weed control treatments, primarily for crop damage and secondarily for weed control.
IV. Second-Level Nursery Screening
Objective: To further investigate crop damage, weed control, economics, and specific concerns such as residual effects in the soil.
V. Operational Trials
Objective: To refine the weed control method and obtain more economic data before operational use.

The current NTC screening program involves phases I and II. Our major crop emphasis so far has been Douglas-fir and ponderosa pine. We will begin screening on other conifers in October 1985. The first phase III experiments are planned for Spring 1986.

As promising, non-phytotoxic chemicals are identified in phases I-III, the NTC will proceed with phases IV and V, culminating (we hope) in new product registrations.

APPLICATION TECHNIQUES

Application Monitors

Improperly calibrated application equipment can lead to costly mistakes. Applications with backpack sprayers and granule spreaders are especially prone to overapplication. Recalibrate the applicator at least once a year. For additional insurance, computerized application monitors are also available ($1500-$2000) and are especially useful for getting better results from applications using low carrier volumes or with herbicides that are applied at very low rates.

Low Carrier Volumes

Low carrier volumes have been found to enhance the herbicidal activity of Poast, Fusilade, and Roundup (glyphosate) (William, 1985; Buhler and Burnside, 1984). Most of these herbicides are applied in 20 or more gallons of water per acre, usually to improve coverage. Weed control with all three herbicides however was found to be better with 10 to 15 gallons of water per acre, perhaps because the individual droplets were more concentrated. When using such low carrier volumes, 80015 or micromax nozzles and emitters are needed.

Backpack Sprayer Comparisons

Nurseries that use backpack sprayers may be interested in a new publication that compares various types of backpack sprayers (Fisher and Deutsch, 1984). This report analyzes 37 different kinds of sprayers. Recommendations of one sprayer over another are not given, but desirable and undesirable features of different sprayers are illustrated.

Split Application

The earlier-mentioned work by Pereira (1985) on nutsedge control and a recent paper by South (1985) have found split applications of herbicides to be more effective than applying the whole recommended dose at once. South notes that the lower dosage, more frequent applications don't let the weeds get too large, and that the smaller weeds are easier to control. More frequent applications of Goal (oxyfluorfen) allow a chemical barrier to be maintained on the soil surface. A drawback to this technique, especially with Goal, is that timing is critical in avoiding crop phytotoxicity. Getting good coverage can also be a problem.

Conclusion

It is always good to keep up with the latest information, but it is also important to prevent and anticipate any weed problems before they occur. Remember also that repeated use of a single herbicide may create more problems than it solves due to the development of resistant weeds or a shift in the weed population to weed species that are tolerant of the herbicide. It is important to use a combination of techniques to have the most efficient and economical weed control.

LITERATURE CITED

Brewster, B.D. 1985. Efficacy of grass herbicides. Pacific Northwest Weed Topics. 84(4):1.

Buhler, D.D. and O.C Burnside. 1984. Effect of application factors on postemergence phytotoxicity of fluazifop-butyl, haloxyfop-methyl and sethoxydim. Weed Science 32:574-583.

Fisher, H.H. and A.E. Deutsch. 1984. Lever operated knapsack sprayers. A practical scrutiny and assessment of features, components and operation. Implications for purchasers, users and manufacturers. International Plant Protection Center, Oregon State University, Corvallis, Oregon. IPPC Document #53-A-84. 32 pages.

Pereira, W. 1985. Yellow nutsedge (*Cyperus esculentus* control with herbicides: the role of tuberization. Ph.D. Thesis (unpub lished). Oregon State University. 161 pages.

Sandquist, R.E., P.W. Owston, and S.E. McDonald 1981. How to test herbicides at forest tr nurseries. USDA Forest Service. Pacific Northwest Forest and Range Experiment Station. General Technical Report PNW-127 24 pages.

South, D.B. and D. Stringfield. 1985. An old application technique proves useful when used with a modern herbicide. Auburn University Southern Forest Nursery Management Cooperature. Report 19. 5 pages.

Whitson, T.D., R.D. William, R. Parker, D.G. Swan, and S. Dewey, compilers. 1985. Pacific Northwest Weed Control Handbook. Extension Services of Oregon State Univers ity, Washing State University, and the Uni versity of Idaho. 213 pages.

William, R.D. 1985. Low water volumes improve Roundup activity. Pacific Northwest Weed Topics. 85(2):8.

Principles, Procedures, and Availability of Seedling Quality Tests[1]

Kenneth R. Munson[2]

Abstract.--As seedling quality tests move from the research to the operational realm, users and potential users must become knowledgeable about the basis for various tests. Without a basic understanding, vigor testing will remain a black-box. This paper condenses and reviews the principles and procedures behind measurements now considered operational: Morphology, mineral nutrition, water status, frost-hardiness, survival, dormancy release, and root growth potential. Tests are now available from three private companies and one university. Seedlings sent for testing should be representative of the lot, and transported in such a way that vigor is not reduced. Cooperative studies to correlate test results and seedling performance in the field are encouraged. The potential benefit of seedling quality testing can be very high relative to the cost.

INTRODUCTION

Seedling quality is a topic that has been .scussed by nursery managers and reforestation resters for several decades. Morphological :aits were the focus of early seedling growers id users, while recently the emphasis has been ı physiological quality, or vigor. Many ethods used to characterize seedling quality iat heretofore were experimental are now being sed as operational tests. Different tests and ifferent reasons for testing are being nployed. At this point in time the usefulness : these tests as a measure of seedling vigor is ased on both intuitive reasoning and empirical vidence.

Operational vigor tests, for such seedling eatures as frost-hardiness and root growth otential, have been available for only a few ears. There is most likely some confusion bout the principles and procedures of the arious tests. Many potential users probably iew vigor testing as a "black box", and are ence rather skeptical to the notion of using igor tests as a means of quantifying seedling uality.

The purpose of this paper is to help larify the issue by briefly reviewing the ationale for seedling quality testing, the ests that are now available on an operational asis, and the principles and procedures upon hich the tests are based. Finally, a listing f organizations which offer a seedling testing ervice, and sampling and shipping ecommendations are provided.

RATIONALE FOR SEEDLING QUALITY TESTING

There are several reasons for testing seedling quality (Faulconer and Thompson 1985; Duryea 1985). From the perspective of a nursery manager, test results can be used to:

- Demonstrate stock quality to a customer.
- Guide the implementation of certain practices.
- Assess the affects of certain practices.
- Cull seedling lots that have a low expected field performance.

On the other hand, a seedling user (regeneration forester) might use test results to:

- Match seedlings with certain characteristics to specific sites.
- Identify if, and at what step, seedling quality falldown occurs during the handling and planting phase.
- Cull seedlings of low vigor before the cost of planting has been incurred.
- Determine if special handling practices are necessary.
- Determine if plantation success or failure was due to stock quality or other factors.

OPERATIONAL TESTS

Many procedures for characterizing seedling quality have been tested (Ritchie 1984), some with more success than others. In his review, Ritchie proposed a logical separation of seedling attributes for which measurements can be made : material attributes and performance attributes. Following is a modified list of these attributes for which tests are considered operational:

Material Attributes	Performance Attributes
o Morphology	o Frost-Hardiness
o Height, stem diameter	o Survival - Unstressed
	o Survival - Stressed

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A few of these measurements require only limited equipment and can be made at the nursery or in the field. Most of the measurements, however, require trained personnel, rather expensive equipment and/or a facility for maintaining constant environmental conditions.

It is important that a user of test information have an understanding or at least an appreciation for the biological basis of each test. Only under this condition can useful interpretations of the data be made.

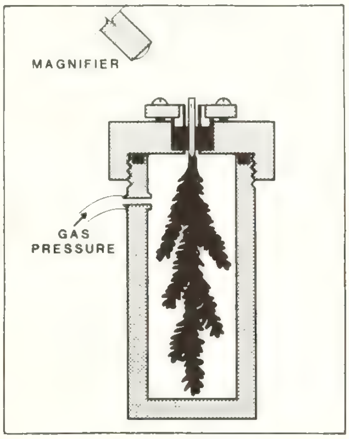
PRINCIPLES AND PROCEDURES

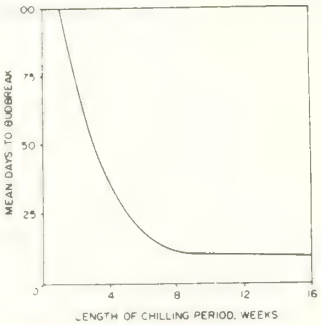
As noted earlier, one purpose of this paper is to capsulize the principles and procedures of the tests that are now considered to be operational. Information about each test will be presented in table form; the reader is referred to specific references for more detail about specific tests.

The following extended table lists the principle(s) upon which a test is based, and a simplified procedure for taking a measurement. This is not intended to serve as a user's guide to vigor testing, but rather an overview from which more detailed inquiries can be made.

Table 1.--Principles upon which seedling quality testing is based, along with simplified measurement procedures.

Attribute	Principle	Procedure	Reference
Morphology			
o Height	o Correlated to needle number, thus a measure of photosynthetic capacity and transpirational area. o Positive relationship between height growth and initial height.	o Meter stick, electronic device o Standard position; e.g., cotyledonary scar to base of bud.	Thompson, 1985
o Diameter	o Better correlated than height to survival. o Good correlation with dry weight. o Larger diameter, more structural support and protection.	o Vernier caliper or simple guage. o Measure at a standardized position. o Stem cross-section is not a uniform diameter.	Thompson, 1985
o Dry Weight	o Correlated to survival and growth as are height and diameter. o Good relationship with photosynthetic area. o Destructive technique. o Easier to use height and/or diameter.	o Rinse tissue, oven dry. o 65° C, 24 hours. o Weigh samples on a balance. o Weigh shoot and root separately to determine ratio.	Thompson, 1985
o Shoot/Root	o Measure of balance between the transpirational area (shoot) and the water absorbing area (root). o Contradictory as an index of field performance.	o Dry weight or volume displacement method. o Shoot weight divided by root weight.	Burdett, 1979
o Bud Height	o Correlated with number of needle primordia and field growth. o Related to vigor at time of dormancy induction.	o Sever bud at base. o Measure with vernier calipers.	Thompson, 1985
Mineral Nutrition	o Certain mineral elements are essential components of plant structure or biochemical functions. o Deficiency of an element will reduce vigor and growth.	o Take good, clean, representative samples. o Stem and foliage for 1-0's, foliage only for older stock. o Oven dry, 65° C, 24 hours. o Grind, dry ash, analyze.	Landis, 1985

Attribute	Principle	Procedure	Reference
Water Status	o Water required to maintain tugor, transport nutrients, facilitate biochemical processes. o If water potential = 0, a plant's water requirements are fully satisfied. o As water content decreases, w.p. becomes more negative (now expressed as megapascals, 1 MPa = 10 bars). o Primary use in irrigation scheduling, dormancy induction and in lifting operation.	o Pressure chamber method.  o Place leaf or stem in chamber. o Increase pressure in chamber with compressed N_2 gas until sap appears at cut surface. o Record pressure on guage.	Joly, 1985
Frost-hardiness	o The susceptibility of seedlings to freezing damage changes naturally with the seasons and artificially with cultural practices. o Hardier seedlings are more resistant to lifting, handling and planting stresses. o Freeze damage is usually dehydration. o Rate of temperature drop and time at minimum temperature are important variables in the test.	o Sample whole seedlings. o Place seedlings in a freezer with a lower minimum temperature of at least -25° C. o Begin at 0° C, drop at 5° C/hr, hold at minimum temperature for 2 hours, raise at 10° C/hr. o Run at 3 temperatures (use fresh samples each time) that bracket LT_{50} (temperature at which 50% die). o Hold seedlings in greenhouse for 1 week, allowing time for damage symptoms to appear. o Evaluate and assign a damage index rating to buds, needles and stem. o Plot numbers on graph paper and interpolate LT_{50}. o Seedlings can also be evaluated with an electrical conductivity meter after freezing. o Uniform test conditions are important.	Glerum, 1985
Dormancy Release	o Dormancy develops in response to environmental signals, but can be influenced by cultural practices. o For seedlings to have maximum vigor, their annual cycle must be in phase with the natural environment. o Relationship between chilling period and days to bud break (refer to graph on next page).	o Whole seedlings are potted and placed in a greenhouse, 20-25° C, 16 hr. daylength. o Held for a set period of time (usually 28 days) and evaluated for terminal and lateral bud burst. o Often done in conjunction with the 28-day root growth potential test. o Data presented as % terminal bud break.	Lavender, 1985

Attribute	Principle	Procedure	Reference
Dormancy Release (Con't)	 o Once chilling requirements have been met, buds become active in response to rising temperatures.		
Survival (Unstressed)	o Observe seedlings under ideal growth conditions. o Should reveal the capacity or potential of a lot to survive.	o Pot 20-30 whole seedlings (or some representative sample), place in a greenhouse. o 20-25° C, 16 hr daylength, 28 days to 2 months. o Tally living and dead seedlings, express as % survival.	McCreary and Duryea, 198
Survival (Stressed)	o Assumes the normal stresses encountered during planting and first-year establishment can be roughly simulated by exposing seedlings to artificial stress. o Roots are probably the most susceptible to damage.	o Sample 30 seedlings, wash roots, pat dry. o Suspend seedlings in a hot, dry chamber or room. o 32° C, 30% humidity, 15 min. o Remove seedlings, place in water for 5 min. o Evaluate for mortality after 2 weeks, 1 month, and 2 months. o Usually done in conjunction with 30 unstressed seedlings.	McCreary and Duryea, 198
Root Growth Potential	o Outplanting survival is often a function of how quickly a seedling re-establishes the intimate contact of its roots with the soil. o This is accomplished by initiating and elongating roots. o RGP is a measure of a seedling's capacity to do so under ideal growing conditions. o RGP accumulates in the nursery and is expressed the following year in early spring. o RGP can be influenced by nursery environment, and cultural and and handling practices. o Good correlations between RGP (at planting) and survival and growth. o Hypothesized that the relationship between RGP and field performance is due to a close linkage between RGP, cold-hardiness, and stress resistance, rather than growth of new roots *per se*.	o Select 20-30 seedlings that represent the lot to be tested. o Wash the roots and pot with a 1:1 mix of peat or perlite : vermiculite. o Water the pots initially, and keep near field capacity. o Place in a greenhouse and maintain as uniform environmental conditions as possible. o 20° or 25° C day/night temperature and 16 hr daylength is satisfactory. o RGP is sensitive to temperature, moisture and light. o After 28 days, quantify new root growth. o Total counts or length measurements may be used, but for practical purposes, tallying root codes is satisfactory.	Ritchie, 1985

ttribute	Principle	Procedure	Reference
Root Growth Potential (Con't)	o RGP is presently the most widely used performance attribute of seedling quality.	Example: Code — Description 0 — No new roots 1 — Some <1 cm 2 — 1- 10 >1 cm 3 — 11- 30 >1 cm 4 — 31- 60 >1 cm 5 — 61-100 >1 cm 6 — 100+ >1 cm o Data can be averaged or expressed as a frequency distribution. Alternate Methods o 7-day growth room test. o 7 or 28 day hydroponic test. o Shorter tests are done at higher temperatures; e.g., 25-30° C.	

RGANIZATIONS OFFERING SEEDLING TESTING SERVICES

Table 2 lists the organizations which now ffer a range of seedling testing services in the orthwest. Most organizations are flexible nough to accommodate special services or andling practices when given advance notice.

Seedling water status is usually measured at the nursery or outplant site. The procedure requires a "pressure chamber," which can be purchased from PMS, Inc. in Corvallis, Oregon (503/752-7926, cost is roughly $1,500).

able 2.--Organizations offering a range of seedling testing services in the Northwest.

	TESTS AVAILABLE								
ource	RGP 28-day	RGP 7-day	Frost-Hardiness	Morphology	Dormancy Release	Survival Un-Stressed	Survival Stressed	Frost Damage Assessment	Special Services
. International Paper Co. 34937 Tennessee Rd. Lebanon, OR 97355 Contact: Ken Munson 503/243-3273 Jay Faulconer 503/259-2651	X		X	X	X	X			X
. Seedling Quality Services 6511 203rd Ave. S.W. Centralia, WA 98531 Contact: Sally Johnson 206/273-9882	X		X	X	X	X		X	X
. MacMillan-Bloedel Ltd. 65 Front St. Nanaimo, BC V9R 5A9 Contact: Glen Dunsworth 604/753-1112		X	X	X	X	X	X		X
. Oregon State University* Dept. of Forest Science Corvallis, OR 97331 Contact: Doug McCreary 503/753-9166					X	X	X		

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*This OSU service will no longer be offered after the 1985/86 testing season.

TISSUE NUTRIENT ANALYSES*

5. Oregon State University
Soil Science Department
Plant Analysis Laboratory
Corvallis, OR 97331
Contact:
Dean Hanson 503/754-2441

6. Oregon State University
Horticulture Department
Corvallis, OR 97331
Contact:
Jim Wernz 503/754-3695

7. Chinook Research Laboratories
333 N. Santiam Hwy.
Lebanon, OR 97355
Contact:
John Burnett 503/259-2488

8. Western Laboratories, Inc.
P. O. Box 400
Parma, ID 83660
Contact:
John Taberna 208/722-6564

9. Soil and Plant Laboratory, Inc.
P. O. Box 1648
Bellevue, WA 98009
Contact:
Dirk Muntean 206/746-6665

* Note: This is a partial list of PNW and Intermountain analytical laboratories. Nearly every land-grant university will have one or more labs. Readers are encouraged to learn of other facilities in their respective states.

SAMPLING AND SHIPPING

A full battery of vigor tests will require 120-150 seedlings. Samples should be representative of the lot as a whole. Depending on the time of year and reason for the test, seedlings can be sampled directly from the nursery bed, the grading line, cold storage or planting site. More than one sample is recommended for seedling lots that occupy large areas in the nursery. The user's judgement is important in determining what constitutes a representative sample.

Seedling samples should be promptly refrigerated (between 2° and 10° C) and transported to the test location. Samples taken from storage should also be kept cool. Warm temperatures for prolonged periods can reduce seedling vigor. Seedlings can be shipped in heavy-duty, wax-coated cardboard boxes or ice chests via a commercial bus, the United Parcel Service, or personal delivery. Since there is always the likelihood of transport problems (such as a seedling lot sitting in a warm bus depot overnight), it is adviseable to notify someone at the test facility that you are sending seedlings and when to expect them. Same day or overnight delivery is preferred.

As a final note, seedling shipments should be scheduled so that weekend deliveries are avoided (unless prior arrangements have been made). Maintaining a close working relationship with the test facility will pay off in more prompt and reliable service and results.

CONCLUSION

The potential benefit of seedling quality testing is very high relative to the cost. Although enough data exist to demonstrate the usefulness of these tests, there is still a need for more complete information about the interaction between seedling quality attributes and site-specific conditions. For example, which seedling traits are most important on droughty sites?, or on moist coastal sites where competing vegetation is the limiting factor? Aside from the seedling aspect, it is also important that a forester be able to determine or predict accurately the growth limiting factors on a site.

Acquiring new knowledge about seedling quality testing will require a close working relationship between the nursery manager, forester and vigor test personnel. As more experiments and field trials confirm and fine-tune the usefulness of these tests, the more the procedure will become a routine part of regeneration practices. On an historical note, when Wakely (1954) proposed morphological grades for culling seedlings, there was undoubtedly reluctance on the part of many nursery managers to discard seedlings simply because they were small. Now morphological grading is a routine practice.

ACKNOWLEDGEMENT

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REFERENCES

Burdett, A. N. 1979. A non-destructive method for measuring the volume of intact plant parts. Can. J. For. Res. 9:120-122.

Duryea, M. L. 1985. Evaluating seedling quality: Importance to reforestation. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 1-4.

aulconer, J. R. and B. E. Thompson. 1985. Benefits of knowing seedling quality. In Proc.: West. and Intmtn. Nurserymen's Assoc. meeting, August 14-16, 1984, U.S. For. Serv. Gen. Tech. Report INT-185, June 1985, pp. 84-87.

lerum, C. 1985. Frost-hardiness of coniferous seedlings: Principles and applications. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 107-123.

oly, R. J. 1985. Techniques for determining seedling water status and their effectiveness in assessing stress. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 17-28.

andis, T. K. 1985. Mineral nutrition as an index of seedling quality. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 29-48.

avender, D. P. 1985. Bud dormancy. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 7-16.

McCreary, D. D., and M. L. Duryea. 1985. OSU vigor test: Principles, procedures, and predictive ability. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 85-92.

Ritchie, G. A. 1985. Root growth potential: Principles procedures and predictive ability. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 98-105.

Ritchie, G. A. 1984. Assessing seedling quality. In: Forest Nursery Manual: Production of bareroot seedlings (M. L. Duryea and T. D. Landis, eds.), Martinus Nijhoff/Dr. W. Junk Publishers, for For. Res. Lab., Oregon State Univ., Corvallis, OR. pp. 243-259.

Thompson, B. E. 1985. Seedling morphological evaluation -- What you can tell by looking. In Proc.: Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. L. Duryea, ed.). Workshop held Oct. 16-18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis, OR. pp. 59-71.

Wakeley, P. C. 1951. Planting the southern pines. USDA For. Serv., S. E. For. Exp. Stn. Occ. Paper 122. 579 p.

When to Measure Seedling Quality in Bareroot Nurseries[1]

David G. Simpson[2]

Abstract.--Quality of bareroot conifer nursery stock is measured (1) during the growing phase, (2) before lifting, and (3) before outplanting. The appropriate tests to make at each times are discussed.

Seedling quality can be described or measured using a wide range of techniques and procedures (Burdett 1983; Chavasse 1980; Ritchie 1984). The rationale for assessing seedling quality, in particular, the principles and procedures for those seedling quality tests presently used on an operational basis are summarized in Ken Munson's paper (this proceedings).

The purpose of my paper is to discuss which, and perhaps more importantly, when are these seedling quality tests used in bareroot nurseries. In the bareroot seedling production cycle, there are three phases when seedling quality tests are used: (1) during the growing season, (2) prior to lifting, and (3) prior to field planting.

MEASURES MADE DURING THE GROWING SEASON

Measurement of seedling quality, particular seedling material attributes (Ritchie 1984) duri the growing season, can help the nurseryman prod a maximum number of saleable seedlings. Morphological measurements of height, stem diameter an dry weights when taken at intervals over a growi season can be used to generate growth curves (fig. 1) for crops. These curves, when repeated for several years, can provide a reasonable pred tion of crop inventories. As well, "fine tuning of fertilizer, root culturing and irrigation regimes can be made so that the maximum number o target quality seedlings are produced.

In British Columbia, tissue nutrient level (N:P:K:Ca:Mg) of 1+0 Douglas-fir (coastal and interior varieties), white spruce, lodgepole pin and Sitka spruce have been determined annually i mid-October since 1968 (van den Driessche 1984). The results of these tests when considered along with the size of the 1+0 seedlings, the target sizes of the 2+0 crop and the "normal" nutrient levels for a particular species x nursery combin

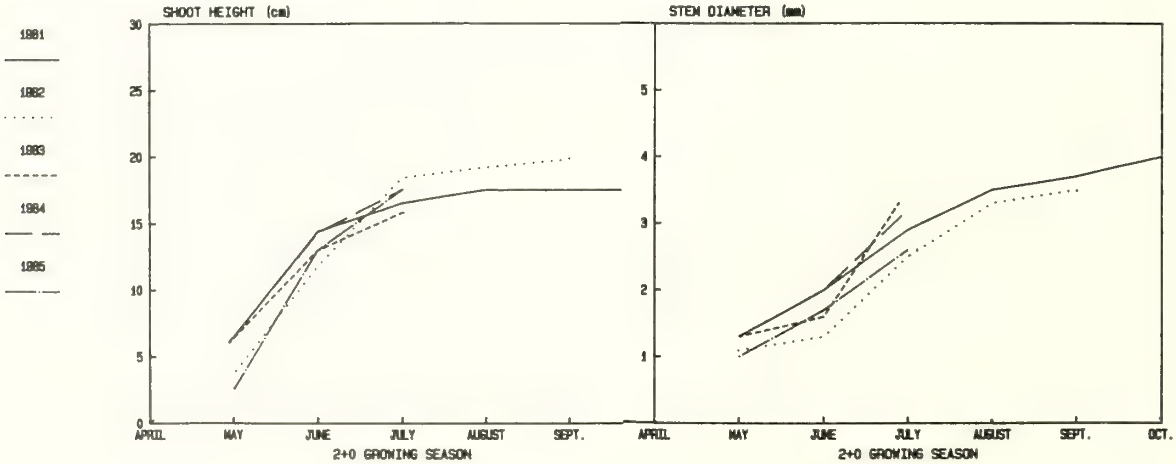

Figure 1.--Shoot height and stem diameter growth of 2+0 interior spruce bareroot seedlings at Skimikin Nursery, Salmon Arm, B.C. Each sample point represents 200 to 250 seedlings.

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[1] Paper presented at the Intermountain Nurserymen's Association meeting, August 13-15, 1985, Fort Collins, CO.

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ion are used to develop the fertilizer regime for ne second growing season.[3] Nutrient analysis uring the growing season is usually used to deter- ine if deviations in projected growth rates, or nysical abnormalities, such as chlorosis, are utrient-related.

For operational use, the most common means to ssess plant moisture stress is to measure xylem ressure potential (XPP) using the pressure chamber ethod (Cleary and Zaerr 1980; Ritchie and Hinckley 975; Waring and Cleary 1967). Moisture stress pplied during the growing season has been reported o result in growth reductions in several conifer pecies (Dykstra 1974; Glerum and Pierpoint 1968; aufmann 1977; Schulte and Marshall 1983; Timmis nd Tanaka 1976; Young and Hanover 1978). The ffectiveness of plant moisture stress as a cul- ural tool to manipulate seedling growth may inter- ct with daylength. Blake et al. (1979) noted that ild moisture stress (pre-dawn xpp of -0.4 to 0.8 MPa) was most effective in reducing shoot:root atios and apical height growth, while increasing oot mass and stem diameter if the stress was pplied in mid-July before natural daylengths hortened. Moisture stress may also be a useful ultural tool in the "hardening" process, parti- ularly with those conifers indigenous to regions ith mid-summer drought, which do not respond uickly to shortening daylengths, or are grown in urseries with longer daylengths (Lavender 1985). oung and Hanover (1978) found dormancy could be mposed using water stress in Colorado blue spruce, ven under 24-hour days; however, this imposed ormancy (quiescence) was released on re-watering. roleptic, or lammas growth in Douglas-fir can also e limited by water stress (Blake et al. 1979).

With the exception of cold hardiness deter- inations, performance attributes (Ritchie 1984) re not usually measured during the growing season. urseries experiencing frosts early or late into he growing seasons often undertake cold hardiness esting to determine if irrigation for frost pro- ection is required.

MEASURES MADE PRIOR TO LIFTING

Seedling quality assessments made at this ime are done so for two reasons: (1) to describe he stock quantity and quality for the nursery ustomer, and (2) to ensure seedlings destined for old/frozen storage are lifted at a time of maximum "storability".

Material attributes, such as standard morpho- ogical assessments, and in some cases, special easurements of resting bud gross morphology Thompson 1985) or needle primordia number (Colombo nd Odlum 1984; Colombo et al. 1982) are approp- iately measured at this time. Tissue nutrient nalysis can be done as there may be field perfor- ance benefits obtained from increased tissue nutrient levels (Landis 1985). Moisture stress (XPP) at lifting can have adverse effects on field performance of stored seedlings (Daniels 1978). Monitoring of XPP using the pressure chamber method (Cleary and Zaerr 1980; Ritchie and Hinckley 1975; Waring and Cleary 1967) during the lifting period would seem a worthwhile process to minimize the stresses associated with lifting, sorting and grading of nursery stock (Burdett and Simpson 1984).

Choice of lifting date can be based on a number of factors: operational considerations, such as staff availability and nursery field access; past experience, or "lifting windows" for specific seedlot x nursery combinations (Jenkinson 1984); or some measure of seedling physiology (Burdett and Simpson 1984) which predicts post-storage vigor or field performance potential. It is immaterial which means of deciding on a lifting date is used so long as the method(s) selected ensure the seedlings provided to the customer at planting time will survive and grow.

In British Columbia, past experience too often has been found to be an unreliable means of determining a lifting date to ensure optimum post-storage seedling vigor. The lifting window method (Jenkinson 1984) used with apparent success in California and the chilling hour accumulation methods used in Ontario (Mullin and Hutchinson 1978) have not been widely used in British Columbia principally because of the large number (>1500) of seedlots and species (17) grown in our nurseries. The wide geographic (48.5 to 60°N and 114 to 139°E) and considerable elevational range (0-2000 m) of seed origins would require considerable effort to generate seed source lifting windows. Thus, it was for both practical and philosophical reasons that research effects were directed towards consideration of several physiological variables which may predict post-storage because of a direct causal relationship, or simply by correlation.

Dormancy and tissue cold hardiness appear to be the most useful performance attributes measurable prior to lifting (Garber and Mexal 1980; Burdett and Simpson 1984). Several techniques to measure dormancy have been used, and are reviewed by Lavender (1985) and Ritchie (1984). Mitotic activity of meristematic shoots (buds), a material attribute, may be a useful tool for predicting when to lift conifer seedlings as Carlson et al. (1980) observed a reduction of mitotic activity in Douglas-fir as fall progressed. Further research is needed, however to ascertain the predictive value of pre-lift mitotic activity measurements as a means of deciding when to lift to overwinter storage. Dormancy release index (Ritchie 1982, 1984; Ritchie and Dunlap 1980) also may be a useful tool in choosing lifting dates. Dormancy release index measurement, however, requires 10 to 60 days. This time requirement limits the practical application of the technique.

Cold hardiness has been implicated as being correlated with seedling storability and thus may be useful in choosing lifting dates (Burdett and Simpson 1984). Several methods of measuring tissue cold hardiness are available and have been amply reviewed by Glerum (1985), Ritchie (1984), Timmis (1976) and Warrington and Rook (1980). Presently in British Columbia, an operational prelifting cold hardiness testing program has sampled seedlings from nearly 25 nurseries. The test utilizes a controlled freeze at 6°C hr^{-1} to -18°C followed in 4 to 10 days by an assessment of foliage mortality. If foliage mortality due to the freezing test is less than 25%, seedlings are judged suitable for lifting to overwinter (ca. 4 to 8 months) frozen (-2°C) storage. The accuracy of the lifting recommendations are checked by determining root regeneration potential after 6 months, -2°C cold storage. In Ontario, an electrical conductivity method (Colombo et al. 1984) of measuring cold hardiness is used to determine if seedlings are sufficiently hardy to overwinter out-of-doors. These conductivity methods, along with the more rapid differential thermal analysis (DTA) technique (Becwar et al. 1981; Sakai 1979, 1982; Wallner et al. 1982) are presently being evaluated as quicker (6 to 48 hours) methods of assessing cold hardiness such that safe lifting dates can be selected.

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[3] Maxwell, J. 1985. Personal conversation. .C. Ministry of Forests, Silviculture Branch, urrey, B.C., Canada.

MEASURES PRIOR TO PLANTING

Fall and winter lifted seedlings that receive overwinter cold storage may exhibit moisture stress in storage if lifted when under moisture stress, packaged incorrectly such that tissue water is lost, or subject to temperature fluctuations during the storage period so that water condenses on the inside of the multi-wall liner bags. The pressure chamber technique has proved a useful monitoring tool to ensure proper lifting, storage and handling practices are followed. In my experience, it is very rare to find overwinter stored seedlings with XPP levels less than -0.5 MPa unless gross mishandling has occurred. On the planting site, however, bareroot seedlings are susceptible to moisture loss during the handling process which may impede growth (Coutts 1982). Using the pressure chamber on the planting site can serve to educate field staff as to their handling effects on seedling water relations. It should be noted, however, that whole plant XPP may not be a sensitive enough measure to detect damage to fine roots (Coutts 1

Presently, there are only two performance attributes which are used to measure seedling quality at, or shortly before, planting. The vi test developed at Oregon State University (Herma and Lavender 1979) has been shown (McCreary and Duryea 1985) to be well correlated with field su vival. Unfortunately, in many circumstances, th 30 days required for damage to develop limits th usefulness of this test. Root growth potential (RGP) testing (Ritchie 1985) using a variety of test conditions and durations has shown generall strong correlation to field performance (Day 198 Sutton 1980, 1983; Burdett 1979; Burdett et al. 1983; Ritchie and Dunlap 1980). Ritchie (1985) describes the tests developed by Stone and his colleagues (Stone 1955; Stone and Schubert 1959(1959(b); Stone and Jenkinson 1970). The standar RGP test requires 28 days; in British Columbia, 7-day test period has been found adequate for growth of large numbers of new roots in most spe x stock types. The RGP test conditions are some arbitrary, but should be chosen such that (1) th strongest correlations with field performance ar obtained, and (2) the best differentiation betwe low and medium vigour stock is attained. For lodgepole pine, 30°C day/25°C night temperature regimes and a 16-hour day with a photosynthetic photon flux density (PPFD) of 400 mol s^{-1}m^{-2} se to produce the most number of new roots (Burdett 1979), while for white spruce and Douglas-fir, cooler regimes appear to result in greater numbe of new roots (figs. 2 and 3). Present operation practice in British Columbia is to use the warme 30°C/25°C regimes for all species as satisfactor correlation between RGP and field performance ha been demonstrated in our major species (spruce, lodgepole pine, Douglas-fir) (Burdett et al. 198 Simpson unpubl. data) at these temperatures, and species grown in British Columbia have been obse to produce roots at these temperatures. Researc underway may, however, result in changes to thes conditions in the future if better correlation w field performance and/or better differentiation low and medium vigour seedlots can be obtained.

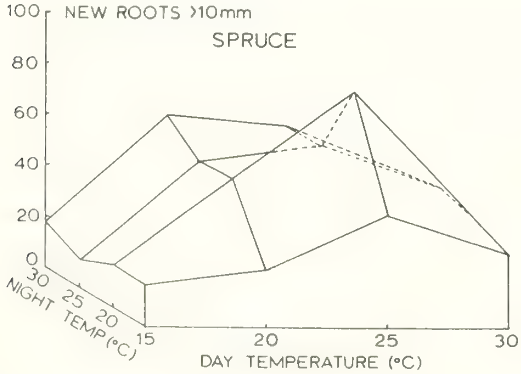

Figure 2.--Day/night temperature regime effects on root growth potential (RGP) of Engelmann spruce container-grown seedlings. Each sample point represents the mean number of new roots >10 mm in a 16-seedling sample.

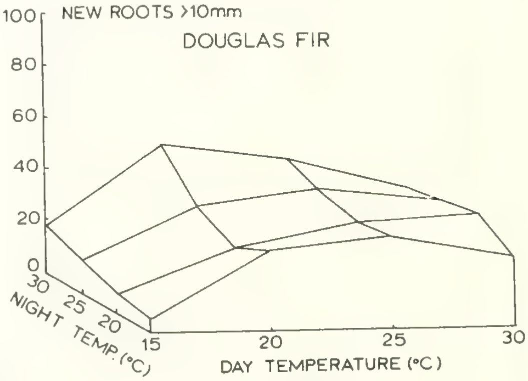

Figure 3.--Day/night temperature regime effects root growth potential (RGP) of Douglas-fir (interior variety) container-grown seedlings Each sample point represents the mean number new roots >10 mm in a 16-seedling sample.

SUMMARY

In bareroot nurseries, seedling quality should be measured using the appropriate tests and during the appropriate phases of the production cycle, these are:

oduction phase	Quality test	Operational objective(s)
owing	- Morphology	- Production targets from curves
	- Nutrient levels	- Ensure maximum growth rates - Avoid deficiencies/excesses
	- PMS	- Ensure maximum growth rates - Dormancy induction
	- Cold hardiness	- Frost protection
e-lifting	- Morphology	- Stock descriptions
	- Nutrient levels	- Possible correlation to field performance
	- PMS	- Avoid stress at lifting
	- Dormancy status	- Predict storability
	- Cold hardiness	- Predict storability
re-planting	- PMS	- Avoid storage and handling stress
	- Vigour test	- Correlated with field performance
	- RGP	- Correlated with field performance

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LITERATURE CITED

ecwar, M.R., C. Rajashekar, K.H. Hanson-Bristow and M.J. Burke. 1981. Deep undercooling of tissue water and winter hardiness limitations in timberline flora. Plant Physiol. 68:111-114.

lake, J., J. Zaerr and S. Hee. 1979. Controlled moisture stress to improve cold hardiness and morphology of Douglas-fir seedlings. For. Sci. 25:576-582.

urdett, A.N. 1979. New methods for measuring root growth capacity: their value in assessing lodgepole pine stock quality. Can. J. For. Res. 9:63-67.

urdett, A.N. 1983. Quality control in the production of forest planting stock. For. Chron. 59:132-138.

urdett, A.N. and D.G. Simpson. 1984. Lifting, grading, packaging, and storing. In Forest nursery manual: Production of bareroot seedlings (Duryea and Landis, eds.) Nijhoff/Junk Publ. for For. Res. Lab., O.S.U., Corvallis, Ore. pp. 227-234.

Burdett, A.N., D.G. Simpson, and C.F. Thompson. 1983. Root development and plantation establishment success. Plant and Soil 71:103-110.

Carlson, W.C., W.D. Binder, C.O. Feenan and C.L. Preisig. 1980. Changes in mitotic index during onset of dormancy in Douglas-fir seedlings. Can. J. For. Res. 10:371-378.

Chavasse, C.G.R. 1980. Planting stock quality: a review of factors affecting performance. N.Z.J. For. 25:144-171.

Cleary, B.D. and J.B. Zaerr. 1980. Pressure chamber techniques for monitoring and evaluating seedling water status. N.Z.J. For. Sci. 10:133-141.

Colombo, S.J. and K.D. Odlum. 1984. Bud development in the 1982-83 overwintered black spruce container seedling crop. Ont. Min. Nat. Resources For. Res. Note 38. 4 p.

Colombo, S.J., C. Glerum and D.P. Webb. 1982. Bud development in black spruce container stock. Ont. Min. Nat. Resources For. Res. Note No. 32. 5 p.

Colombo, S.J., D.P. Webb and C. Glerum. 1984. Frost hardiness testing: an operational monitoring manual for use with extended greenhouse culture. Ont. Min. Nat. Resources For. Res. Rep. No. 110. 14 p.

Coutts, M.P. 1981. Water relations of Sitka spruce seedlings after root damage. Ann. Bot. 49:661-668.

Coutts, M.P. 1982. Effects of root or shoot exposure before planting on water relations, growth, and survival of Sitka spruce. Can. J. For. Res. 11:703-709.

Daniels, T.G. 1978. The effect of winter plant moisture stress on survival and growth of 2+0 Douglas-fir seedlings. M.S. thesis. Ore. St. Univ., Corvallis, Ore. 86 p.

Day, R.J. 1982. Evaluating root regenration potential of bareroot nursery stock. *In* Proc. Intermountain Nurserymen's Assoc. Meeting. Can. For. Serv. Infor. Rep. NOR-X-241. pp. 83-86.

Dykstra, G.F. 1974. Drought resistance of lodgepole pine seedlings in relation to provenance and tree water potential. B.C. For. Serv. Res. Note 62. 7 p.

Garber, M.P. and J.G. Mexal. 1980. Lift and storage practices: their impact on successful establishment of southern pine plantations. N.Z.J. For. Sci. 10:72-82.

Glerum, C. 1985. Frost hardiness of coniferous seedlings: principles and applications. *In* Proc. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests. (M. Duryea, ed.). For. Res. Lab., Ore. St. Univ., Corvallis, Ore. pp. 107-123.

Glerum, C. and G. Pierpoint. 1968. The influence of soil moisture deficits on seedlings growth of three coniferous species. For. Chron. 44:26-29.

Hermann, R.K. and D.P. Lavender. 1979. Testing the vigor of coniferous planting stock. Ore. St. Univ. For. Res. Lab. Res. Note No. 63. 3 p.

Jenkinson, J.L. 1984. Seed source lifting windows improve plantation establishment of Pacific slope Douglas-fir. *In* Seedling physiology and reforestation success (Duryea and Brown, eds.). Nijhoff/Junk Publ. Dordrecht, The Netherlands. pp. 115-141.

Kaufmann, M.R. 1977. Soil temperature and drought effects on growth of Monterey pine. For. Sci. 23:317-325.

Landis, T.D. 1985. Mineral nutrition as an index of seedling quality. *In* Proc. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. Duryea, ed.) Ore. St. Univ. For. Res. Lab., Corvallis, Ore. pp. 29-48.

Lavender, D.P. 1985. Bud Dormancy. *In* Proc. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. Duryea, ed.) Ore. St. Univ. For. Res. Lab., Corvallis, Ore. pp. 7-15.

McCreary, D.D. and M.L. Duryea. 1985. OSU vigor test: principles, procedures and predictive ability. *In* Proc. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests (M. Duryea, ed.) Ore. St. Univ. For. Res. Lab., Corvallis, Ore. pp. 85-92.

Mullin, R.E. and R.E. Hutchinson. 1978. Fall lifting dates, overwinter storage, and white pine seedling performance. For. Chron. 54:261-264.

Ritchie, G.A. 1982. Effect of freezer storage on bud dormancy release in Douglas-fir seedlings. Can. J. For. Res. 14:186-190.

Ritchie, G.A. 1984. Assessing seedling quality In Forest nursery manual: Production of bar root seedlings (Duryea and Landis, eds.) Nijhoff/Junk Publ. for For. Res. Lab., Ore. St. Univ., Corvallis, Ore. pp. 243-259.

Ritchie, G.A. 1985. Root growth potential: pri ciples, procedures, and predictive ability. *In* Proc. Evaluating seedling quality: principles, procedures, and predictive abilitie of major tests (M. Duryea, ed.) Ore. St. U For. Res. Lab., Corvallis, Ore. pp. 93-105

Ritchie, G.A. and J.R. Dunlap. 1980. Root grow potential: its development and expression i forest tree seedlings. N.Z.J. For. Sci. 10 218-248.

Ritchie, G.A. and T.M. Hinckley. 1975. The pressure chamber as an instrument for ecolo gical research. Advances in Ecological Res 9:165-254.

Sakai, A. 1979. Freezing avoidance mechanism o primordial shoots of conifer buds. Plant a Cell Physiol. 20:1381-1390.

Sakai, A. 1982. Extraorgan freezing of winter of conifers. *In* Plant cold hardiness and freezing stress. Vol. 2 (P.H. Li and A. Sa eds.). Academic Press, NY. pp. 199-209.

Schulte, P.J. and P.E. Marshall. 1983. Growth water relations of black locust and pine se lings exposed to controlled water stress. Can. J. For. Res. 13:334-338.

Sutton, R.F. 1980. Planting stock quality, roo growth capacity, and field performance of t boreal conifers. N.Z.J. For. Sci. 10:54-71

Sutton, R.F. 1983. Root growth capacity: relat ship with field root growth and performance in outplanted jack pine and blue spruce. P and Soil 71:111-122.

Stone, E.C. 1955. Poor survival and the physio logical condition of planting stock. For. Sci. 1:90-94.

Stone, E.C. and J.L. Jenkinson. 1970. Influenc of soil water on root growth capacity of ponderosa pine transplants. For. Sci. 16:2 239.(cited by Ritchie 1985).

Stone, E.C. and G.H. Schubert. 1959(a). Season periodicity in root regeneration of pondero pine transplants -- a physiological conditi Proc. Soc. Amer. Foresters. pp. 154-155. (Cited by Ritchie 1985).

Stone, E.C. and G.H. Schubert. 1959(b). The ph logical condition of ponderosa pine (*Pinus ponderosa* Laws.) planting stock as it affec survival after cold storage. J. of Forestr 57:837-841. (Cited by Ritchie 1985).

Thompson, B.E. 1985. Seedling morphological evaluation - what you can tell by looking. Proc. Evaluating seedling quality: principl procedures and predictive abilities of majo tests (M. Duryea, ed.) Ore. St. Univ. For. Lab., Corvallis, Ore. pp. 59-71

Timmis, R. 1976. Methods of screening tree see lings for frost hardiness. *In* Tree Physiol and Yield Improvement. (Cannell and Last, Academic Press, NY. pp. 421-435.

Timmis, R. and Y. Tanaka. 1976. Effects of con tainer density and plant water stress on gr and cold hardiness of Douglas-fir seedlings For. Sci. 22:167-172.

van den Driessche, R. 1984. Soil fertility in forest nurseries. In Forest nursery manual: Production of bareroot seedlings (Duryea and Landis, eds.) Nijhoff/Junk Publ. for For. Res. Lab., Ore. St. Univ., Corvallis, Ore. pp. 63-74.

Wallner, S.J., J.E. Bourque, T.D. Landis, S.E. McDonald and R.W. Tinus. 1982. Cold hardiness testing of container seedlings. In Proc. 1981 Intermountain Nurserymen's Assoc. Meeting. Can. For. Serv. Info. Rep. NOR-X-241. pp. 21-25.

Waring, R.H. and B.D. Cleary. 1967. Plant Moisture Stress: evaluation by pressure bomb. Science 155:1248-1254.

Warrington, I.J. and D.A. Rook. 1980. Evaluation of techniques used in determining frost tolerance of forest planting stock: a review. N.Z.J. For. Sci. 10:116-132.

Young, E. and J.W. Hanover. 1978. Effects of temperature, nutrients and moisture stresses on dormancy of blue spruce seedlings under continuous light. For. Sci. 24:458-467.

How to Use Seedling Quality Measurement in Container Nurseries[1]

C. J. Sally Johnson[2]

Abstract--The various techniques for measuring seedling quality are discussed in relation to the time of testing. How the data thus gathered can be applied to cultural practice alternatives is also discussed with a common sense approach to growing seedlings.

There is a wide range of seedling quality tests available and these have been discussed quite adequately elsewhere (Burdett 1983, Chavasse 1980, Ritchie 1984). The procedures for these tests are covered in Ken Munson's paper (pp 71-77).

The purpose of this paper is to discuss how to use the data gained from these tests over the life of a crop to produce a better seedling.

MEASURES MADE DURING THE GROWING SEASON

Morphological measurements which consist of height, caliper, shoot and root dry weights and--late in the season--bud heights can generate growth curves over time and provide an indicator of how well your crop is doing in meeting size specifications required by your customers. Water and nutrient regimes can be used to increase or decrease growth as needed during the growing season. You need to keep in mind time and climate constraints. The unwise practice of extending the active growth of seedlings into the late fall and early winter could have some disastrous effects on your crop. Top growth must cease early enough to allow bud development in later summer. Good bud development requires short days and warm temperatures. If active top growth is continued into September, there will not be enough warm temperatures to ensure proper bud development after the cessation of growth. Root development also takes place in the fall and again, if top growth is extended, the gains in seedling height will be made at the expense of root development. Root dry weights can continue to increase through October and if the height growth has ceased in August, good root mass is the result.

Very little has been written on minimum specifications for root mass and bud size, but experience and common sense can give some indication of where to start. Root dry weights of .40 grams in Douglas fir grown in a 2.0 cubic centimeter container are adequate or better. This root mass will hold its configuration when extracted and provide adequate or better root growth capacities when there are no physiologica problems present such as disease. Root dry weights of .30 grams or less usually do not maintain their integrity and generally have lower ro growth capacities. Seedlings with finer root systems such as spruce, hemlock and cedar have a adequate root mass at .30 grams. Bud heights in Douglas fir are adquate at 4.0 centimeters. This is measured from the base of the bud where the bud scales begin to the top of the bud. Buds less than four centimeters tall tend to be poorly developed and are usually less frost-hardy than larger buds. Bud heights indicate growth potential for the following year and thus are very important to your customers.

Determining the nutrient levels of tissue is a very important tool for the container grower. The opportunity is there to get rapid results by altering the nutrient regime according to seedling needs for either more or less growth. Each grower needs to establish a nutrient regime suitable for his particular species, the geographical origin of stock, the container sizes and the geographical location of his facility. All of these things will affect the growth of the crop. It is best to use a reputable lab which will provide the expertise in interpreting the nutritiona data in the beginning. Later, after the grower has gained some experience with his particular situation, he can prepare his own fertilizer prescriptions. One caution to remember in designing nutrient regimes is that what may work for one grower with his unique combination of species stock types and geographical location may not work for another.

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[1] Paper presented at the Intermountain Nurserymen's Association meeting, August 13-15, 1985, Fort Collins, CO.

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Most growers use some form of moisture tress treatment to induce dormancy at the end f the growing season. The most common method f measuring plant moisture stress (PMS) is the ressure chamber method (Cleary and Zaerr 1980; itchey and Hinckley 1975). On the other hand, igh levels of PMS during the growing season ill reduce seedling size. The pressure bomb an be used to keep PMS levels low during the eriod of active growth and then keep the PMS evels high enough to induce dormancy, but not o high that damage is done to the seedlings. any growers rely on block weights to determine he need for irrigation both during active rowth and the hardening-off phase. This method equires considerable experience in determining ow to irrigate by the weight of various-sized locks. Block weights can vary depending on the onsistency of the media, size of seedlings and everal other factors. The PMS measurements are more direct measurement of the moisture status f the seedlings.

MEASURES MADE PRIOR TO LIFTING

This is the time when the finished product s checked for overall quality to ensure that he seedlings are ready for the stresses of storge and outplanting and thus have a good chance f surviving in the field.

Morphological characteristics are the most ommonly used measures of seedling quality mployed at the time of packing. Almost all eedlings must meet predetermined height and aliper standards to be considered saleable. Alhough these attributes have failed to predict ield survival in the past as accurately as we eed, they are still important, and we need to ontinue to use these attributes as a measure of eedling quality. In order to better predict uccessful plantation establishment, we need to dd more morphological attributes as well as ome physiological attributes that are to be disussed later. The morphological attributes we eed to add to our specifications are bud height nd root dry weight. These two attributes will nsure we have good enough bud and root developent to ensure good growth and survival in the ield, which are critical for good plantation stablishment. There are other methods for easuring these attributes and these are disussed in Dave Simpson's paper (pp 78-83). The ud heights and root dry weights, however, are he simplest methods being used operationally at his time. These are also specifications that an be given a number and written into the seeding growing contract.

There are various methods of determining he best time to lift seedlings for storage lifting window) and again, Dave Simpson has disussed these methods more fully. Cold-hardiness s being used operationally for this in a number f areas and is a relatively rapid way to deterine readiness for storage (Burdett and Simpson 1984; Glerum 1985). Lifting windows may vary with seed source, species, yearly climate fluctuations and cultural practice regimes. This is, again, a situation where each grower needs to become fa-iliar with how his unique situation affects the lifting window for his stock.

Cold-hardiness levels may also be needed to ensure survival in the field when below freezing temperatures are expected shortly after planting, particularly in the case of fall planting. The situation often arises when seedlings are being grown a considerable distance from the seed origin. For instance, Intermountain seed sources are being grown in the Pacific Northwest. In this case, the frost hardiness development of the seedlings whose origins are in Idaho, but who are hardened off in Oregon will be less than if the seedlings were hardened off in Idaho (Unpublished data, Johnson, 1985). This can cause losses due to cold damage in the field. It is wise to keep this in mind when growing seedlings not from your own seed zone.

MEASURES PRIOR TO PLANTING

Assuming that all seedlings have already been graded for morphological attributes, we now need to determine the physiological state of the seedlings prior to outplanting. Overwinter storage of seedlings can either be in a controlled cooler or freezer or, in many cases, be uncontrolled outside storage. The controlled units are, of course, preferable, as uncontrolled storage usually depends on a snowfall prior to the onset of very cold temperatures to protect seedlings from cold damage. As everyone knows, some years you get the snow and some years you don't. Even controlled storage units can malfunction, allowing the seedlings to experience damaging temperatures. To ensure that no deterioration of stock quality has taken place during the period of storage, a root growth capacity test is in order. Most operational root growth tests available take place in a controlled environment at relatively warm temperatures with an extended photoperiod. The duration of the test is approximately thirty days. Interpreting root growth data is in the initial stages in many areas of the western United States, but we do have enough experience to give some helpful hints for interpreting the test results. Root growth capacity values that may prove satisfactory in Western Washington may not be satisfactory in Colorado. The severity of the planting site will determine what root growth capacity is adequate. Seedlings that produce any new roots at all in the thirty day period have a chance of surviving, given the right conditions. However, seedlings that produce fewer than 30 new roots over one centimeter in length during the test have a poor chance of survival on the dry sites of the San Juan National Forest (Unpublished data, Johnson 1985). The seedlings producing fewer than 11 new roots over one centimeter have a poor chance of survival in the better sites of the Olympic National Forest in Washington (Unpublished data, Johnson 1985). Experience has also shown that seedlings that fail to produce over 30 new roots over one centimeter during the test usually have something wrong with them. The problem may be inadequate root mass, damaged roots or dead roots due to disease, overwatering, etc. One- to two-year-old seedlings of most, if not all, species of conifers are capable of producing over 50 new roots over one centimeter in length within the 30-day test with a fairly high rate of frequency; therefore, expecting a minimum of 30 new roots over one centimeter is a very realistic goal.

SUMMARY

Seedling quality tests can provide valuable assistance to the grower to produce a quality product that has the best chance of survival and growth in the field. The recommended tests can best be utilized as follows:

Operation	Test	Objective(s)
Growing	-Morphology	-Meet targets from growth curves
	-Nutrient levels	-Ensure maximum growth rates -Avoid deficiencies/toxic levels
	-PMS	-Ensure maximum growth rates -Induce dormancy
Pre-lifting	-Morphology	-Desirable stock with set specifications
	-Cold-hardiness	-Predict storability
Pre-planting	-Root growth capacity	-Correlate to field performance

LITERATURE CITED

Burdett, A. N. 1983. Quality control in the production of forest planting stock. For. Chron. 59:132-138.

Burdett, A. N. and D. C. Simpson 1984. Lifting, grading, packaging, and storing. In Forest Nursery manual: Production of bareroot seedlings (Duryea and Landis, eds.) Nijhoff/ Junk Publ. For. Res. Lab., O.S.U., Corvallis, OR, pp. 227-234.

Chavasse, C. O. R. 1980. Planting stock quality: a review of factors affecting performance. N. Z. J. For. 25:144-171.

Cleary, B. D. and J. B. Zaerr, 1980. Pressure chamber techniques for monitoring and evaluating seedling water status. N. Z. J. For. Sci. 10:133-141.

Glerum, C. 1985. Frost hardiness of coniferous seedlings: principles and applications. In Proc. Evaluating seedling quality: prin ciples, procedures, and predictive abilitie of major tests. (M. Duryea, ed.). For. Res Lab., O.S.U., Corvallis, OR, pp. 107-123.

Ritchie, G. A. 1984. Assessing seedling qualit In Forest Nursery manual: Production of bareroot seedlings (Duryea and Landis, eds. Nijhoff/Junk Publ. for For. Res. Lab., O.S.U., Corvallis, OR, pp. 243-259.

Ritchie, G. A. and T. M. Hinckley 1975. The pressure chamber as an instrument for ecological research. Advances in Ecological Res. 9:165-254.

How to Determine Fertilizer Rates and Application Timing in Bareroot Forest Nurseries[1]

T. D. Landis and J. W. Fischer [2]

Abstract.--The uptake and utilization of N, P, and K is affected by nutrient characteristics, seedling factors and nursery environment. Fertilization plans should be customized to reflect individual nursery characteristics. Fertilizer application rates can be determined through soil testing or by crop use. Timing of fertilizer applications varies between nutrients based on nutrient characteristics and seedling response.

The use of fertilizer in forest tree nurseries is generally considered to be a routine cultural operation and many nursery managers apply fertilizers on traditional calendar dates according to some general guidelines. Fertilizers supply a significant portion of the mineral nutrients needed for seedling growth, particularly of the major "fertilizer elements": nitrogen (N), phosphorus (P), and potassium (K). Fertilization has been shown to effect both the quantity and quality of seedling growth and, therefore, application of the correct amount of fertilizer at the proper time is critically important to the production of high-quality seedlings.

FACTORS AFFECTING FERTILIZER NUTRIENT UTILIZATION BY TREE SEEDLINGS

The uptake and utilization of mineral nutrients is affected by a variety of factors related to the seedling itself, to the nursery environment, and specific to the individual fertilizer ions.

Seedling Development

All three fertilizer nutrients are required in relatively large amounts by young seedlings but the actual uptake patterns vary. The amount of P stored in the seed is quite limited and therefore supplies of this nutrient are required almost immediately after germination. Armson (1960) studied the uptake patterns of N, P, and K and found that P was rapidly taken up early in the 1+0 growing season and again later in the year (Figure 1A). N and K, on the other hand, have high early uptake rates which gradually drop off during the growing season; this pattern closely follows the pattern for net seedling growth as represented by the net assimilation rate (Figure 1B). These data suggest that P should be made available to the plant both early and late in the growing season whereas N and K should be supplied during periods of seedling growth.

Species of Seedling

Different tree seedlings have different growth characteristics and therefore require mineral nutrients in different amounts. Rapidly-growing pioneer species, such as jack pine (*Pinus banksiana)* and quaking aspen (*Populus tremuloides)*, require lower amounts of fertility (particularly N) than slower-growing spruces or ash (Stoeckeler and Arneman, 1960). Some nursery managers do not add any supplemental fertilizer to the seedbeds of aspen or western larch (*Larix occidentalis)* in an effort to control height growth whereas spruces or true firs are heavily fertilized to force height growth.

Seedbed Density

The number of seedlings growing per unit area of seedbed has a significant effect on their nutrient uptake. Most nursery workers are familiar with the "dished", chlorotic pattern in seedbeds suffering from N deficiency; this condition exists because seedlings in the interior of the seedbed are under more competition and receive relatively less N than seedlings near the edge (Armson and Sadreika, 1979). This effect of seedbed density varies between species, however, as van den Driessche (1984a) found that Douglas-fir *(Pseudotsuga menziesii)* and Sitka spruce *(Picea sitchensis)* were more sensitive than lodgepole pine *(Pinus contorta)*.

Many nursery managers do not appreciate the very high growing density of tree seedlings compared to agricultural crops. If we assume a seedbed density of 25 seedlings per sq.ft. and a field efficiency of 60%, the resultant growing density of 650,000 seedlings per acre would be extremely high, compared to a typical density of 20,000 plants per acre for corn.

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[1] Paper presented at the Intermountain Nurseryman's Meeting, August 13-15, 1985, Ft. Collins, CO.

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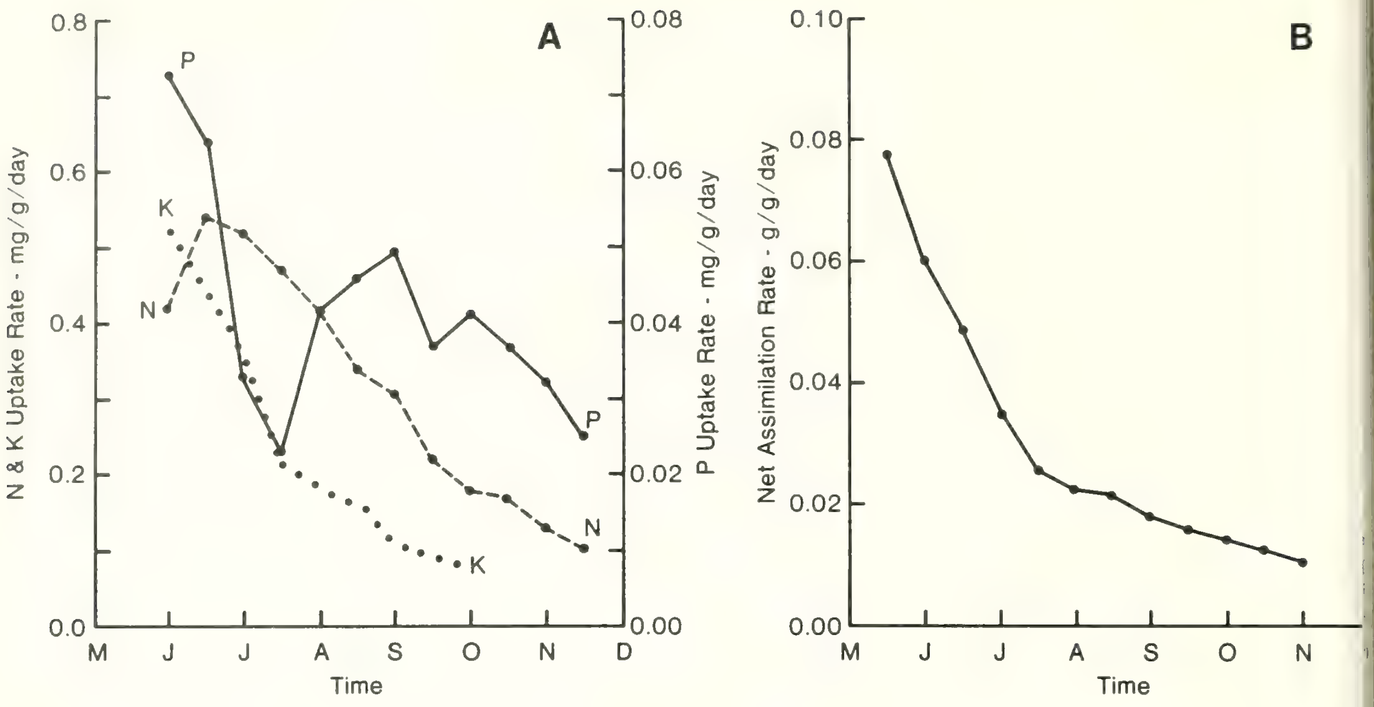

Figure 1.--(A) Comparison of nutrient uptake rates of N, P, and K, with (B) seedling growth rate during the growing season (modified from Armson, 1960).

Temperature

The effect of temperature on nutrient uptake is not surprising but few people realize how significant it can be. A study by van den Driessche (1984b) shows that seedling growth is severely restricted below 10°C, regardless of the level of P fertilization; this growth reduction is very abrupt which suggests that root function is impaired at low temperatures (Fig. 2). Because this is a general physiological effect rather than a specific ion effect, this temperature restriction probably occurs for all mineral nutrients.

Moisture

Soil moisture levels can affect mineral nutrient uptake in several different ways. Nutrient uptake due to mass flow occurs when ions dissolved in the soil solution move with the soil water towards the roots during transpirational uptake. Nutrient absorption is greatest when soil moisture is at field capacity which gives the ideal balance of both water and air. Low soil water content reduces nutrient uptake directly because the resultant low hydraulic conductivity restricts water movement whereas saturated soils reduce nutrient uptake indirectly because the anaerobic conditions adversely affect root and microbial activity.

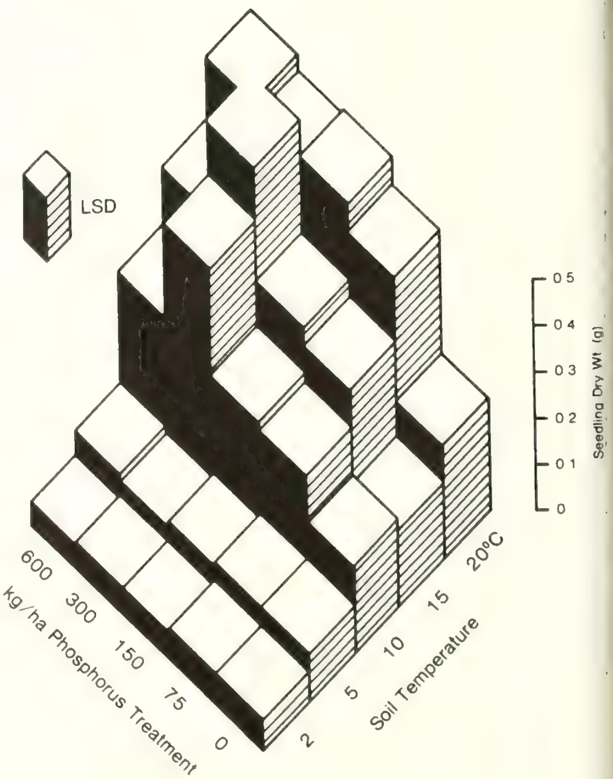

Figure 2.--The effect of soil temperature and phosphorus fertilization rates on Douglas-fi seedling growth (van den Driessche, 1984b).

Table 1.--Characteristics of fertilizer nutrients that influence fertilizer application and timing.

Fertilizer Elements	Nutrient Mobility and Leaching Potential		Time of Peak Nutrient Demand	Fertilizer Application Method	Timing
Nitrogen	NO_3^-	High	During rapid growth periods	Top Dressing	At regular intervals (4-5X per season)
	NH_4^-	Medium			
Phosphorus	$P_2O_5^-$	Low	Early and late in growing season	Incorporation or Banding	Pre-sowing
Potassium	K^+	Medium	During rapid growth periods	Incorporation and Top Dressing	Half-presowing and Half-midseason

Characteristics of Individual Fertilizer Ions

Each of the three fertilizer elements acts ifferently in the soil depending on its electri-al charge and other chemical properties. Nitrate NO_3^-) is a negatively-charged anion and is very obile in the soil and subject to leaching because nions are not held on the negatively-charged ation exchange sites (CEC). The phosphate ion $P_2O_5^-$) is also an anion but only about 1% of the otal P in the soil is in this available form. ost of the soil P is unavailable because it is sually chemically bound by a number of other ons in the soil and so its mobility and leaching otential are low. K^+ and ammonium -N (NH_4^+) are ositively-charged cations that can be bound on he CEC complex; both ions are moderately subject o leaching (Table 1).

These characteristics, in combination with he time of peak nutrient demand, should be onsidered for both fertilizer application method nd timing (Table 1). N fertilizers should be pplied as top-dressings at regular intervals hroughout the season so that a constant supply f nutrient is available. P is normally applied s a presowing incorporation or banded during owing to insure that the immobile P ions are vailable to the young seedlings. K fertilizers re often applied both as an incorporation at he beginning of the season and again as a top ressing about midseason.

WAYS TO ESTABLISH A FERTILIZER APPLICATION PLAN

Every bareroot nursery needs a fertilization lan - a systematic, documented approach describing ertilizer application practices. Each of these lans will be different and will reflect the haracteristics of the individual nursery. Most ertilization plans are established using one or ore of the following:

1. Personal experience - This is probably he most common and certainly the most traditional ay to set up a fertilization program. As in any arming operation, nursery managers can build up real expertise based on their experiences over he years. In addition to keen powers of observation, nursery workers should have a basic understanding of fertilizer action and soil science in order to learn what works best at their own nursery. The real limitation to this method, however, is the time required to accumulate this experience. Because of the multi-year rotations inherent in tree production, a person must remain at the nursery long enough to witness several different rotations and experience a range of weather and crop variation.

2. Recommendations - This category includes both advice from consultants and recommendations from technical articles and nursery manuals. Nursery consultants are able to visit individual nurseries and learn specifics about soil factors, crop characteristics, and climatic conditions and develop a customized fertilizer program. On the other hand, consultants are expensive and can be addictive - a nursery manager could become overly dependent on outside assistance. Nursery manuals and technical articles usually give "generic" fertilizer recommendations and the nursery manager must be able to modify these recommendations to fit his own conditions and species.

3. Nursery Fertilizer Trials - Undoubtedly the best way to develop a fertilization program is to conduct a series of fertilizer trials right in the nursery so that specific crop responses can be measured. Ideally, trials should be performed on each major soil type and species of seedling, and also should be conducted over several rotations so that all sources of variation can be sampled. Nursery managers should seek the assistance of a statistician or nursery specialist in the planning stages and during the interpretation of nursery fertilization trials.

4. Soil Testing - Most tree nurseries have had soil tests performed at one time or another but many managers are not comfortable with their own interpretation of the test values. Soil tests are a good way to monitor soil fertility and fertilizer response but they have certain limitations. Most tests report in terms of "available" nutrients but these values vary with the extracting solution used in the lab; these extracting solutions supposedly remove the same amount of nutrient that would be available to the tree

seedling. P availability is particularly hard to measure and testing labs across the country use a variety of different extracting solutions which give different P availability values. Although any agricultural soil testing lab can perform soil tests, most are not familiar enough with tree seedlings to provide relevant interpretation of the results. Most published soil fertility standards for tree seedlings have usually developed from fertility trials with one of the major commercial species such as Douglas-fir and may not be applicable to other species of seedlings. Soil testing can also be an expensive operation, especially if the recommended number of samples is taken, so nursery managers should make sure that the cost of the test includes interpretation and recommended fertilizer treatments. Consultants can be very helpful in the interpretation of test results and their fee is usually very worthwhile.

5. Seedling Nutrient Analysis (SNA) - As with soil tests, SNA is expensive but can be invaluable because it is the only real way to determine if the nutrients applied as a fertilizer are ever taken up by the seedling. Interpretation of the test results can be difficult and many of the published standards are ranges of values that may not be sensitive enough to detect a problem with one particular species. Assistance with interpretation is often required and again consultants can be helpful.

CALCULATION OF FERTILIZER APPLICATION RATES

The amount of fertilizer that should be applied to a nursery seedbed can be determined by soil test results or crop use. Maintenance fertilizer applications maintain soil fertility at some target level and are based on soil tests and/or SNA. Replacement applications replace the nutrients used by the seedling crop during the year. P and K are usually applied as maintenance applications using target values for the nutrients (Table 2). Soil N exists in many organic and inorganic forms in nursery soils and there is no widely-accepted test for available N; therefore, N fertilizers are normally applied as replacement applications.

Table 2.--Soil Test Nutrient Targets for Nurseries of the Inland West

Fertilizer Element	Units	Target
Nitrogen (N)		
Total N	%	0.10 to 0.20
Nitrate -N	ppm	25 to 50
Phosphorus (P)[1]		
Available P	ppm	20 to 50
Available P_2O_5	lbs/ac	92 to 230
Potassium (K)		
Available K	ppm	100 to 150
Available K_2O	lbs/ac	240 to 360

[1] Using Olsen's sodium bicarbonate procedure

The type of fertilizer to apply is very important and single element fertilizers (e.g. ammonium sulfate [21-0-0]) are generally recommen so that fertilizer amendments can be directed at specific nutrient element. Complete fertilizers (e.g. 15-15-15) should not normally be used becau there is usually no need to supply N-P-K at the same application. Complete fertilizers are also more expensive than most single element fertilize Ammonium phosphates (e.g. 18-46-0) are exceptions because these multi-nutrient fertilizers are sometimes applied as pre-sowing incorporations o in bands during sowing.

Replacement Applications of N

N applications are generally applied based on estimates of crop use because there is no acceptable soil test for available N. van den Driessche (1980) reported that 2+0 conifer crops use from 45-178 lbs/ac (50-200 kg/ac) of N durin a rotation. The actual amount of N that a tree seedling crop requires is dependent on species, seedbed density, climate and soil type. Fertili nutrient recovery is also relatively low ranging from 13-16% N for a 1+0 crop to perhaps 50% duri the 2+0 year (van den Driessche, 1984c). N recommendations vary but some examples from rece nursery manuals are provided in Table 3.

Table 3.--Recommended Nitrogen (N) Application Rates Per Year

		Seedlings		Transpla
Source	Units	1+0	2+0	X+1
Armson and	lbs/ac	50-200	60-200	40-150
Sadreika (1979)	kg/ha	56-224	67-224	45-168
Aldhous (1975)	lbs/ac	28-100	28-100	45-90
	kg/ha	25-75	25-75	50-100
van den Driessche	lbs/ac	0-107	100-147	80-160
(1984c)	kg/ha	0-120	112-165	90-180
Stoeckeler and	lbs/ac	40-80	40-80	40-80
Slabaugh (1965)	kg/ha	36-71	36-71	36-71

SNA should also be used at the end of the growing season to monitor the actual amount of N that the seedlings are able to take up and this information can then be used to fine-tune fertilizer applications during the following season. SNA can also be used for trouble shooti during the season if nutrient deficiency symptom such as chlorosis or dished beds become evident. When collecting samples be sure to collect both symptomatic and normal seedlings so that compari can be made. Target values for N in conifer needle tissue range from 1.20 to 2.00% (Table 4) which are very broad; each nursery should strive to accumulate enough data to develop standards for their own species.

ble 4.--Standard Values for Mineral Nutrient Concentrations in Conifer Needle Tissue (Landis, 1985)

neral Nutrient	Units % dry wt	Adequate Range [1]
acronutrients		
N	%	1.20 to 2.00
P	%	0.10 to 0.20
K	%	0.30 to 0.80
Ca	%	0.20 to 0.50
Mg	%	0.10 to 0.15
S	%	0.10 to 0.20
icronutrients		
Fe	ppm	50 to 100
Mn	ppm	100 to 5000
Zn	ppm	10 to 125
Cu	ppm	4 to 12
Mo	ppm	0.05 to 0.25
B	ppm	10 to 100
Cl	ppm	10 to 3000

[1] Macronutrient values are from Youngberg 984) and micronutrient values from Powers (1974)

Maintenance Applications of P and K

Soil test targets for P and K are usually ven in parts per million (ppm) or pounds per acre bs/ac) (Table 2). The ppm units can be converted amount of fertilizer per acre using the process ovided in Table 5. This process uses a standard ight of 4,000,000 lbs for an acre-foot of loam il (or 2,000,000 lbs/6 in. rooting depth) which a reasonable approximation and allows the nursery nager to compute the actual amount of fertilizer quired to maintain the soil fertility at the sired levels.

Although P fertilizer applications should be mputed using the calculations in Table 5, many rtilizer specialists recommend that a starter se of P be incorporated into the seedbed or nded at the time of sowing regardless of the il test level. The root system of the newly rminated seedling is very restricted whereas the mand for P is high during seed germination and rly seedling growth; these starter applications lp insure that a supply of P is readily accessible. n den Driessche (1984c) recommends applying monium phosphate (11-55-0) at a rate of 27 lbs/ac 0 kg/ha) in a band 3 to 5 inches below the drill w and reports a substantial increase in growth r spruce seedlings. Unfortunately, most of the andard seed drills used in forest tree nurseries re not equipped for banding although the conversion ould not be difficult. An opportunity also xists to use the commercial mycorrhizal applicator anufactured by Whitfield as a band fertilizator pplicator; this applicator costs approximately 4500 and is compatible with most nursery seeders R. A. Whitfield Forestry Manufacturing Co., ableton, GA).

Table 5.--Determining Fertilizer Application Rates from Soil Test Results[1]

1. Determine amount of nutrient needed

$$\begin{array}{rl} \text{Target P Level} = & 35 \text{ ppm} \\ - \ \underline{\text{Soil Test Level} =} & \underline{18 \text{ ppm}} \\ \text{Need to add as fertilizer} = & 17 \text{ ppm} \end{array}$$

2. Convert ppm to lbs/ac

$$17 \text{ ppm} = \frac{17 \text{ parts}}{1{,}000{,}000 \text{ parts}} = \frac{17 \text{ lbs}}{1{,}000{,}000 \text{ lbs}}$$

Given: One acre of soil 6" deep (plow-slice) weights 2×10^6 lbs

$$\frac{17 \text{ lbs}}{1{,}000{,}000 \text{ lbs}} = \frac{X}{2{,}000{,}000 \text{ lbs}}$$

$X = 34$ lbs/ac P

3. Convert from P to P_2O_5

34 lbs/ac x 2.3 = 78.2 lbs/ac P_2O_5

4. Convert to weight of bulk fertilizer

Concentrated superphosphate (0-46-0) contains 46% P_2O_5

$$\frac{78 \text{ lbs/ac } P_2O_5}{0.46} = 169.6 \text{ lbs of 0-46-0 per acre}$$

[1] This same procedure can be used to determine K application rates by substituting 1.2 for 2.3 to convert from K to K_2O in Step 3, and using the appropriate bulk fertilizer conversion in Step 4.

K fertilization is not normally required in western nurseries because most western soils contain an abundance of K-bearing minerals, particularly in the Great Plains and Intermountain areas. Nursery managers should utilize soil tests, however, to determine the K availability at their own specific nurseries.

SNA should also be used to monitor P and K fertilizer uptake at the end of each growing season or for trouble shooting during the season. General guidelines for the normal range of P and K are given in Table 4; these should be useful until each nursery is able to develop their own standards.

FERTILIZER APPLICATION TIMING

Once the total annual fertilizer application rate has been calculated, the problem of when to apply the fertilizer and the rate per application must be decided. Because of the different characteristics of these three fertilizer nutrients (Table 1), they will be discussed separately.

Nitrogen - This nutrient is normally applied in a series of small applications over the growing season (Table 6). Because all N fertilizers are water soluble, they are applied as top dressings with standard fertilizer spreaders; N fertilizers can burn succulent seedling foliage and so the fertilizer should be brushed from the foliage or watered-in immediately. The first application of N is usually delayed until after the seedlings have become established because of concern about stimulating damping-off fungi and the possibility of fertilizer burn. During the 2+0 year, however, N fertilizers should be applied as early as possible so that the nutrients are available prior to the first flush of spring growth. Because N is so soluble in the soil, repeat applications may be necessary after heavy spring rains particularly in light-textured soils.

Table 6.--Application Timing of N Top Dressings (Aldhous, 1975 and others)

Crop	Season	Number of Fertilizer Applications Initial	Subsequent
Seedlings	1+0	5-7 weeks after germination or when primary needles appear	At 3-4 week intervals [1]
	2+0	As early as possible	At 3-4 week intervals [1]
Transplants	X+1	At least 1 month after transplanting	At 4-5 week intervals [1]

[1] Repeat applications may be necessary after heavy rains.

One of the most scientific ways of determ the proper time for N applications is the degr day system which uses accumulated heat units. degree day approach is attractive because the fertilizer applications are synchronized with seedling growth which, of course, is also tight linked to temperature. Either ambient or soil temperature can be used as a degree-day basis although soil temperatures are more stable and accurately reflect the environment where the nutrient uptake is actually occurring. Becaus climatic and edaphic variation, each nursery mu develop its own degree day system but an examp of the degree day schedule used for Ontario nurseries is given in Table 7.

Table 7.--Cumulative Degree Days (1°C basis)[1] be used to Schedule N Fertilizer Applicati (Armson and Sadreika, 1979)

Application No.	Southern Ontario Jack and Scots Pine	Others	Northern Onta Jack Pine	Oth
1	55	55	55	5
2	440	220	330	15
3	1100	440	660	30
4	1650	1100	1320	45
5	--	1650	1760	60
6	--	2310	--	90
7	--	--	--	140
8	--	--	--	180

[1] Although not specified, these values are presumably air temperatures.

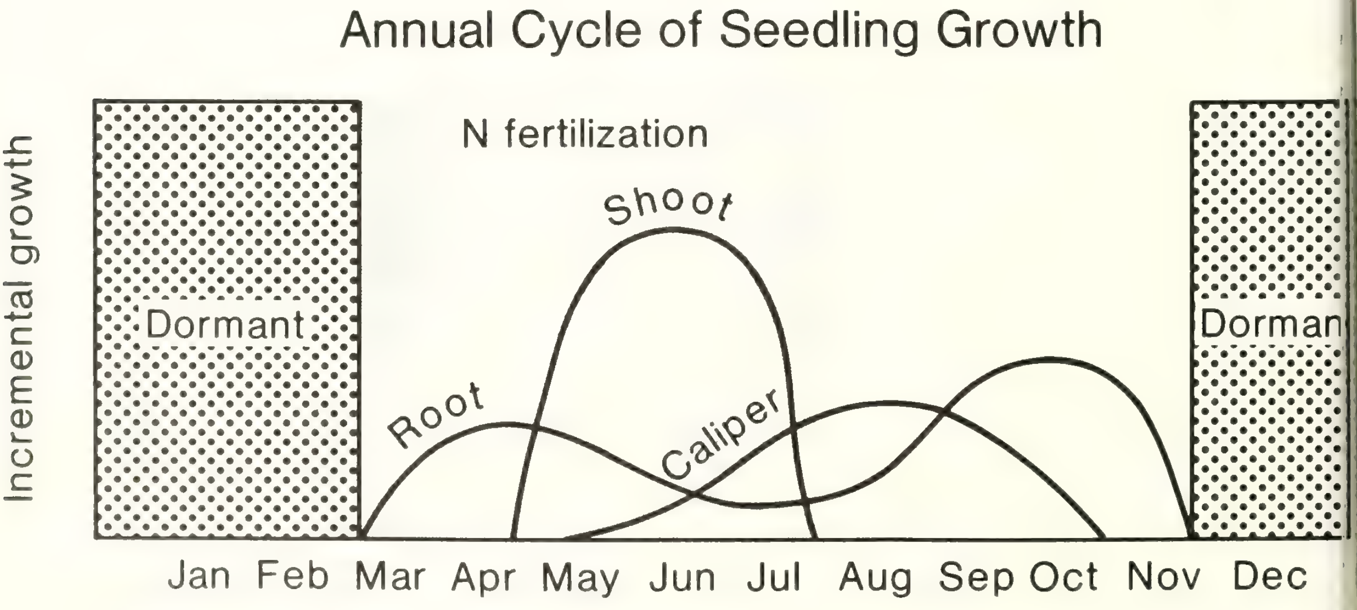

Figure 3.-- Nitrogen (N) fertilization should be scheduled early in the growing season during the period of rapid growth.

If a degree day schedule is not available, he next best procedure is to schedule N fertilizer pplications based on seedling growth curves. lots of growth increments (Fig. 3) show the times hen growth generally occurs and so fertilizer pplications can be scheduled at regular intervals uring this period. This approach insures that he fertilizer is available during the time of aximum seedling growth rather than later in the ear when the fertilizer would be wasted or could dversely affect the onset of dormancy or frost ardiness.

Phosphorus - P applications can be applied uring the fallow year or prior to sowing so that he nutrient is available early in the growing eason (Table 1); these presowing applications re effective because of the immobility of P in he soil. Fallow year applications are applied o the cover or green manure crop so that the P an be fixed into the organic matter and slowly eleased in subsequent growing seasons. Many oil scientists feel that P is best applied mmediately before or at the time of sowing to inimize the potential for chemical immobilization. uptake is temperature dependent (Fig. 2) and so t is important that adequate supplies are availble during the early spring. Mycorrhizae are ery important in the P nutrition of tree eedlings and many young seedlings do not become ycorrhizal until late in the 1+0 season, specially in fumigated seedbeds; this early ycorrhizal deficiency is further justification or presowing P applications. Banding P fertiliers below the seed is especially effective and s discussed in the section on P application rates.

Potassium - K is moderately mobile in the soil nd is required during periods of active growth and an therefore be applied as either a top dressing r incorporated (Table 1). Leaching losses are ore serious in sandy soils with a low CEC so requent top dressings would be more appropriate nder these conditions. Probably the most practical rocedure would be to apply half the annual amount s a presowing incorporation and the other half as midseason top dressing.

CONCLUSIONS AND RECOMMENDATIONS

The utilization of fertilizer nutrients by ree seedlings is affected by many factors including eedling development, species of seedling, seedbed ensity, soil temperature, and soil moisture. The haracteristics of the individual fertilizer lements (N, P, and K) also affects their vailability and utilization in nursery soils.

All bareroot nurseries should develop a ertilization plan which is a systematic, documented pproach to fertilizer use. Fertilization plans ust be developed specifically for individual urseries to reflect unique climatic and edaphic haracteristics and the response of individual eedling species. These plans can be developed sing several different procedures: personal xperience, recommendations, nursery fertilizer rials, soil testing and seedling nutrient analysis. Ideally, nursery managers will use a combination of all 5 of these procedures to produce a balanced fertilization plan. These plans are not permanently fixed, however, and managers must be flexible enough to accommodate new information into their fertilization plans.

Fertilizer application rates can be determined by soil testing or crop use. Both P and K are applied based on soil test results: the amount of nutrient that is required to bring the soil level up to a target level is calculated and then maintenance applications of fertilizer are used to make up the deficiency. Because there is no practical soil test for available N in nursery soils, replacement applications of N fertilizer are generally applied to replace the N used by the seedlings during the year.

The timing of fertilizer applications is also different for each of the fertilizer elements. N is normally applied as a series of top dressings during the growing season. Degree days or seedling growth curves can be used to synchronize N applications with periods of active seedling growth. P is normally applied during the fallow year, incorporated into the seedbed prior to sowing, or banded during sowing so that adequate P is available during the early part of the growing season. K fertilizer applications may be applied either as a presowing incorporation, a top dressing, or both, depending on leaching potential.

LITERATURE CITED

Aldhous, J. R. 1975. Nursery practice. Forestry Commission Bull. No. 43, Her Majesty's Stationery Office, London. 184 p.

Armson, K. A. 1960. White spruce *(Picea glauca* [Moench]Voss) seedlings: the growth and seasonal absorption of N, P, and K. University of Toronto, Forestry Bull. 6, 37 p.

Armson, K. A. and V. Sadreika. 1979. Forest tree nursery soil management and related practices. Ontario Min. of Nat. Res., Toronto. 179 p.

Landis, T. D. 1985. Mineral nutrition as an index of seedling quality. p. 29-48 IN: M. L. Duryea (ed.). Proceedings: Evaluating Seedling Quality: principles, procedures, and predictive abilities of major tests. Workshop held Oct. 16-18, 1984. Forestry Res. Lab., Oregon State Univ., Corvallis.

Powers, R. F. 1974. Evaluating fertilizer programs using soil analysis, foliar analysis and bioassy methods. p. 124-151 IN: Service-wide Work Conf. Proc., Sacramento, CA, USDA-Forest Service, Div. Timber Management, Washington, DC.

Stoeckeler, J. H. and H. F. Arneman. 1960. Fertilizers in forestry. Adv. in Agronomy 12:127-195.

Stoeckeler, J. H. and P. E. Slabaugh. 1965. Conifer nursery practice in the prairie-plains. USDA Forest Service, Agr. Handbook 279, 93 p.

van den Driessche, R. 1984a. Relationship between spacing and nitrogen fertilization of seedlings in the nursery, seedling mineral nutrition, and outplanting performance. Can. J. For. Res. 14:431-436.

van den Driessche, R. 1984b. Response of Douglas-fir seedlings to phosphorus fertilization and influence of temperature on this response. Plant and Soil 80:155-169.

van den Driessche, R. 1984c. Soil fertility in forest nurseries. IN: M. L. Duryea and T. D. Landis (eds.). Forest nursery manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr. W. Junk, The Hague.

van den Driessche, R. 1980. Health, vigor, and quality of conifer seedlings in relation to nursery soil fertility. p. 100-120. IN: Proc. North American Forest Tree Nursery Soils Workshop, held July 28-August 1, 1980 at Syracuse, NY, State University of New York, College of Environmental Science and Forestry, Syracuse.

Youngberg, C. T. 1984. Soil and tissue analysis tools for maintaining soil fertility. p. 75-80. IN: M. L. Duryea and T. D. Landis (eds.). Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr. W. Junk, The Hague.

Soil Mapping and Testing[1]

RANDY SELIG[2]

To manage a modern forest tree seedling nursery properly, one needs some knowledge of the soil resource and its variation within the nursery. A soils map fulfills this need, and enables managers to utilize the resource effectively. Soils maps help nursery managers delineate locations where limiting factors such as shallow depth, poor drainage, salt slicks, or the presence of stones impair crop growth. A soils map is the basis for all soil sampling. Soil nutrient content measured in these samples gives some basis for annual fertilizer prescriptions.

OIL MAPS

ypes of Maps

oil maps prepared by the Soil Conservation Serice are available for much of the private land n the United States. These maps delineate soil eries as they vary over the landscape. Auxiliay S.C.S. materials describe the specific properies and uses of each soil series. The usual ange of surface textural class will tell one enerally the various proportions of sand, silt, nd clay in the different mapping units. Other roperties described include soil depth, texture, H, presence of stones, layers that restrict crop rowth, drainage class, and agricultural suitaility.

ost maps prepared by the S.C.S. are not very deailed. It is possible to have a more intensive urvey completed by the S.C.S. or by consulting oil scientists. Some nurseries have taken samles or field-textured their soils in grid patterns as close as 100 feet by 100 feet. This is time-consuming procedure that may not be necesary at sites that are reasonably homogeneous.

amples generated during the mapping process hould be either sent to a lab for particle size nalysis or field textured to determine textural lass. These same samples could also be analyzed or such basic chemical properties as organic mater (OM), cation exchange capacity (CEC), or pH. aps of these chemical properties will assist in lanning future amendment programs and annual ertilizer prescriptions.

ap Uses

ne of the greatest benefits of a S.C.S. map or other textural class map is that it helps us see the variation in the soil resource. Different textural class soils have inherently different fertilities and retain nutrients differently. A good map will guide our sampling schemes so that different soils are sampled separately for nutrient analysis. Table 1 shows average values for three chemical properties of eight sandy loam fields and five clay loam fields at the Colorado State Forest Service Nursery. The sandy loams at this nursery had consistently lower pH, lower CEC's and less organic matter than did the clay loam fields. A good soil map will help keep these soils separate when sampling for nutrient analysis so that nutritional differences are not blurred.

TABLE I

SOIL TEST RESULTS FROM COLORADO STATE FOREST SERVICE NURSERY

	pH	OM -%-	CEC meg/100g
SANDY LOAM[1]	7.3	2.2	11.7
CLAY LOAM[2]	8.3	3.1	17.0

[1] Ave. of 8 fields

[2] Ave. of 5 fields

SOIL TESTING

Sampling

Knowing the physical properties of the soil resource helps us sample similar soils together and improves the quality of samples taken for chemical analyses. In order to take a representative sample of each sampling unit, we need to follow several procedures carefully. For a detailed description of soil sampling procedures, please refer to F. M. Solon's paper in the Proceedings of the North American Forest Tree Nursery Soils Workshop or to Walsh and Beaton (1973).

Paper presented to the Intermountain Nursery ssociation meeting August 13-15, 1985, Fort ollins, CO.

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Soil samples should be composite samples which are representative of a homogeneous area. Many subsamples are taken, mixed, and sometimes subsampled again. Bulking a large number of samples in this fashion reduces the effect that individual sample variation will have giving an average or mean value. Some soil scientists recommend traversing a sampling area in a large "W" taking samples along all four sides of the "W". Two W's superimposed, one upside-down on the other would represent a very thorough sampling pattern.

One composited sample can be taken for every acre or for several homogeneous acres depending on the soil's variability. Larger sampling areas need more sample cores to adequately represent that area. At least 12 cores should be taken even for an area one acre in size.

Nurseries should divide their fields into sampling areas. A 12-acre field might be divided into three to six sample areas which are internally homogeneous with respect to textural class and organic matter content. Every rotation when this field is sampled for nutrient analysis, samples would be taken from the same sampling areas as in previous years. This procedure enables nursery managers to compare soil tests from different years and to detect long-term trends such as changes in pH or OM.

There is a seasonal variation in some soil chemical values which may be of sufficient magnitude to make comparisons between samples of the same site taken at different times of the year meaningless. The exact time of year samples are taken is less important than consistently sampling in the same season year after year. Sampling sometime after seedling harvest works well if results come back from the laboratory in sufficient time to order fertilizer for the next rotation. If soil pH needs to be modified, early sampling will prove helpful by allowing time for incorporation and reaction to take place before sowing the next seedling crop. Other nurseries sample in late summer before or after fumigation because the soils are well-worked, and it is easy to obtain a good sample.

Laboratory Selection

There are many good laboratories available to analyze soil samples. Finding a good lab and staying with it will help reduce the variation in the results which could be caused by laboratories using different procedures. A good laboratory will run standard samples of soil with each batch of test samples processed. If the standard sample does not test in the accepted range for that sample, the whole batch of samples will be redone. Nurseries can double-check their lab by always sending in the same 'dummy' sample whose chemical contents are known and checking to make sure the results are in the proper range.

Soil Tests

Soil tests are not a measure of total nutrient elements but give us a chemical index of extractable nutrients which may or may not be plant available. Agronomists in a given region can often tell farmers what quantities of fertilizer to add to a certain soil 'type' to achieve a target yield of corn or wheat. This information does not exist for forest seedlings because of t diversity of nursery soils and vast array of species grown. Although most labs are not qualified or are unable to tell nursery managers how to fertilize their crop, the soil tests results are still of value. Nursery managers need to develop a recordkeeping system that will enable them to correlate soil tests with crop productic

Some standard values for soil nutrient levels have been published (Youngberg, 1984; van den Driessche, 1984; van den Driessche, 1980). Most of the available guidelines are for high rainfal areas and are not strictly usable in areas of lower rainfall and higher pH. Since soils at different nurseries seldom share common genetic or mineralogic development, it would be unfair expect all sites to test or respond the same. Field plot experiments with two fertilizer rates and a control can add insight as to appropriate fertilization regimes and corresponding soil te values.

Nitrogen

Although N is the most commonly added fertilizer element, it is seldom prescribed through inspection of soil tests results. Tests for total nitrogen (TN) primarily indicate the amounts of organic nitrogen that are present since the inorganic fraction is small and dynamic. A test f organic matter (OM) might supply the same inforr tion indirectly since C/N of organic materials and soils is fairly constant in sites without large inputs of organic materials.

Other soil tests analyze for the main inorganic forms of mineral N, nitrate (NO_3-) and ammonium (NH_4+). Since most nurseries probably add suff cient irrigation water to leach the inorganic N out of the seedling root zone, these tests are of limited utility. Fertilizer nitrogen rates are most commonly determined by experimentation

Phosphorus

Most soil tests for available P are quite reliable. Different procedures are used depending the acidity or alkalinity of the soil. There i no one soil test value all nurseries should try to achieve. The chemistry of P availability is quite complex and is highly pH dependent so tha different types of soil could supply adequate P at very different test levels. In most cases, is highly advisable to add some P before sowing because small seedlings have a very large need P before they become mycorrhizal. Since P does not move readily in the soil profile, the entir P supply for a 2+0 rotation should be incorpora shortly before sowing. Some nurseries have ver low P concentrations and need to apply large quantities of P fertilizer. Other nurseries ha

gh P soil test values from years of heavy fer-
lization and only need to add smaller quantities
P fertilizer. The most desirable procedure
ld be to band small amounts of granular P
rtilizer below the seed at sowing. Drills with
rtilizer attachments do not seem to be avail-
le yet.

changeable Bases

e majority of cations in any soil system are
nerally the bases potassium (K), calcium (Ca),
d magnesium (Mg). These three are referred to
exchangeable bases and are determined in the
me soil extract. Most soils in the arid and
mi-arid west with near neutral or higher pH
ve adequate Ca and Mg. Potassium may or may not
adequate and should be maintained above 200
m. If the sum of the exchangeable K, Ca, and
exceeds the total cation exchange capacity,
e should also test for electrical conductivity
ometimes called soluble salts) and for free
lcium carbonate ($CaCO_3$).

I

I is a dynamic soil property which should be
utinely determined before sowing. pH exerts a
ntrolling influence on nutrient availability so
at maintenance of pH in the proper range is of
eat importance. Conifer seedlings are quite
nsitive to high pH, usually preferring a range
om five to six. Hardwoods are more tolerant of
igh pH and some species can be successfully
own at pH values over seven.

ils with pH values greater than 7.5 should also
e tested for free calcium carbonate; soils with
I's greater than eight should be tested for the
resence of exchangeable sodium (Na) and for
lectrical conductivity (EC). Both free $CaCO_3$
d Na will interfere with nutrient absorption for
st forest tree seedlings. Sites with these con-
itions whould be avoided if possible because
heir amelioration is costly and time consuming.

rganic Matter

he organic content of a soil is determined by
limate, topographic position, soil texture, and
ropping practices. Most nursery soils slowly
ecrease in organic matter due to soil removal
n harvest and frequent tillage. A toil test for
rganic matter (OM) done every rotation may indi-
ate such a trend and its magnitude.

urseries with aggressive amendment programs may
e forestalling the decline in OM which comes
ith tillage, erosion, and harvest losses. For
hese nurseries a carbon-nitrogen ration (C/N)
etermined by the laboratory in conjunction with
he OM tests can be helpful in determining if the
mendment is adequately broken down or if more N
s necessary to help decompose the C. C/N
reater than 25 or 30 might indicate a need for
dditional N.

Seedling Nutrient Analysis

In contrast to soil tests which tell us 'extracted' nutrients, seedling nutrient analysis (SNA) is a direct indicator of available nutrients. Seedling nutrient analysis tells one the total nutrients the seedling contain usually expressed as a concentration, either percent or ppm. Unfortunately, many biotic and abiotic factors such as drainage, compaction, temperature, microrganisms, etc., conspire to decrease the uptake or availability of soil nutrients which may be present in adequate quantities in the soil. These factors complicate the interpretation of SNA.

Sampling

Seedling nutrient content changes radically as seedlings grow and mature. Most experts recommend sampling during the time of year when values are most stable. For evergreen species, this stable 'plateau' usually coincides with deep dormancy in mid-winter. Foliate analysis is used extensively with deciduous fruit trees; these leaves are usually sampled after leaf expansion has finished in July or August. Samples should be transported to the lab immediately.

Interpretation

Analysis of seedlings with extreme nutrient deficiencies may not yield meaningful results when sampled during the dormant period. The lack of one nutrient element will have altered seedling physiology making all the nutrients out of balance. Interpretation of these numbers as in the case of alkaline soil induced iron deficiency is impossible. Sometimes better foliage analysis results can be obtained by sampling tissue at the first sign of deficiency symptoms. Comparison of paired samples of symptomatic and asymptomatic seedlings may reveal an incipient shortage of some nutrient which could be supplied by additional fertilization.

Standard values for seedling nutrient content can be found in some review articles such as those cited in the bibliography. Most of the published work relates to Douglas-fir and other important timber species. Specific values for windbreak species and less important timber crops are hard to find. A few general guidelines for minimum nutrient content can be excerpted from the literature. For instance, N almost always ranges between one and two percent, P should be at least 0.15 percent, and most species accumulate at least 0.5 percent K.

Bibliography

1. Solon, F. M. 1980. "Soil and plant tissue techniques for tree nurseries." Pages 228-235 in: Proc. North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry.

2. van den Driessche, R. 1984. "Soil fertility in forest nurseries." Pages 63-74 in: Forest Nursery Manual (Mary L. Duryea and Thomas D. Landis, eds.). Forest Research Laboratory, OSU, Corvallis, OR.

3. van den Driessche, R. 1980. "Health, vigour, and quality of conifer seedlings in relation to nursery soil fertility." Pages 100-120 in: Proc. North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry, Syracuse.

4. Walsh, L. M. and James D. Beaton. 1973. Soil testing and plant analysis. Soil Science Society of America, Inc., Madison, WI.

5. Youngberg, Chet. 1984. "Soil and tissue analysis: tools for maintaining soil fertility." Pages 75-80 in: Forest Nursery Manual (Mary L. Duryea and Thomas D. Landis eds.). Forest Research Laboratory, OSU, Corvallis, OR.

How to Maximize Efficiency of Fertilizers in a Forest Tree Nursery[1]

Ivor K. Edwards[2]

Abstract

The essentiality of nitrogen, phosphorus, and potassium was reviewed. Knowledge of the reaction of these nutrients in soil is a prerequisite to efficient use of nitrogen, phosphorus, and potassium fertilizers in forest nurseries. Notwithstanding economic considerations, biological requirements are strong determinants of nursery fertilization procedures.

INTRODUCTION

In order to maximize the effects of fertili- tion in a bareroot tree nursery, it must be alized that nutrition like temperature, mois- re, light energy, and soil factors, strongly fluences plant growth and development. It is cessary to know the characteristics of nutrient ements, their function in the plant, the form which they are preferentially absorbed by tree ecies, properties of the chemical compounds at are being applied, and the interaction of rtilizer products with different soils. Al- ough there are six major and six minor elements at are essential for plant growth, the scope of is report is confined to a discussion of those st common in commercial fertilizers, namely trogen (N), phosphorus (P), and potassium (K). order to optimize a tree nursery operation, is also necessary to apply the fertilizers st effectively. Fertilizers differ in cost roughout North America depending on the cost of eir various components. Application costs will discussed in the context of bareroot seedling roduction in the Canadian Prairies.

CHARACTERISTICS OF NUTRIENTS

itrogen: Function in Plants

Nitrogen moves readily in plants and is a bile element in the soil. It is absorbed most commonly as nitrate (NO_3^-) and ammonium (NH_4^+) ions and less so as urea ($(NH_2)_2CO$). Within the plant, all forms of nitrogen are converted initially to the amide (NH_2) form and later combine with carboxyl groups to form amino acids, the building blocks of proteins (Tisdale and Nelson 1966). Nitrogen is an integral part of the chlorophyll molecule. Adequate N produces vigorous vegetative growth with deep green color whereas stunted chlorotic plants result from a deficiency of N. Deficiency symptoms appear first on older foliage because N is readily translocated to the meristematic region. At suboptimal levels of N, carbohydrates are deposited in vegetative cells but are converted to proteins as N increases. Excess N causes succulence and results in weakening of cell walls. The vegetative phase is prolonged and maturity is delayed, predisposing the crop to frost and insect damage.

Fate of Fertilizer N in Soil

Nitrate - NO_3

Fertilizer N exists in one or more of three forms, namely nitrate, ammonium, and urea. Nitrate nitrogen is mobile in soil and is subject to loss by leaching predominantly because it moves readily with soil water. Nitrate is not strongly held on the soil exchange complex because of its negative charge. Thus, irrigation and the presence of coarse textured soils (a combination common in many bareroot tree nurseries) lead to leaching loss of nitrate from the root zone.

Since nitrate moves readily with soil water, it also moves upwards with capillary water during dry weather and may be deposited in surface or near surface soil horizons following evaporation.

Nitrate is lost also through denitrification by bacterial conversion to ammonium N and eventually to gaseous N (volatilization). Poor

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drainage, impaired soil oxygen, and alkaline conditions contribute to denitrification.

Nitrate N is subject to assimilation by soil microorganisms especially in the presence of organic material with a high carbon:nitrogen ratio such as sawdust. N is released only when the microbial activity declines.

Ammonium - NH_4

The primary reaction of the NH_4^+ ion is nitrification whereby ammonium N undergoes bacterial conversion to nitrate. Warm (30°C), moist (field capacity), and well aerated soils accentuate nitrification. Ammonium N is subject also to immobilization by microorganisms in the presence of organic material of high C:N ratio. Nitrogen is released through mineralization only when microbial activity declines as the energy source of the bacteria is depleted. Therefore, if organic material with a wide C:N ratio such as grain straw or sawdust, is added to nursery seedbeds, sufficient N should be added simultaneously to satisfy bacterial and plant needs.

The ammonium ion is absorbed more strongly than nitrate by soil colloids owing to its positive charge and therefore is less prone to leaching by percolating water. Its retention in soil is fostered by high cation exchange capacity, and by soil conditions that are unfavorable for nitrification, e.g., low temperature, excess soil moisture. However, conditions (waterlogging and oxygen deficiency) that favor denitrification should be avoided.

In alkaline soil, the ammonium ion is converted to gaseous ammonia and is subject to loss through volatilization. Deep placement, i.e. well within the root zone, adequate mixing, and avoidance of hot, windy conditions during application of ammonium fertilizers will minimize N loss. Ammonium fertilizers increase acidity generally because nitrification is an acid-forming process.

Urea - $(NH_2)_2CO$

In soil, urea reacts with water, i.e., hydrolyzes, to form initially ammonium carbonate and subsequently free ammonia, ammonium ions, and carbonate ions. The initial hydrolysis is aided by the enzyme urease and because it is rapid, seedlings may be damaged by the ammonia released. Nitrogen loss through volatilization is minimized by deep placement. However, fate of the ammonium ion, once formed, will be controlled by plant uptake and factors that affect nitrification and immobilization as explained earlier. The immediate effect of urea fertilizer is to increase soil pH but as nitrification progresses, pH is reduced.

Nitrogen Forms and Seedling Growth

Among conifers, the preferred form of N varies with tree species. In Saskatchewan, 3-0 jac pine (Pinus banksiana) produced best growth in terms of height and dry weight with either ammon um sulphate or calcium nitrate (Edwards 1981). White spruce (Picea glauca) on the other hand gr best with ammonium N. In British Columbia, Douglas-fir (Pseudotsuga menziesii) grew best wi the ammonium form of N (van den Driessche 1984).

It should be pointed out that soil properti play an important role in maximizing the efficie cy of applied N. Since ammonium fertilizers are acid forming, they promote uptake of N in soils in which soil pH is unsuitably high. Ammonium sulphate, for example, is prescribed repeatedly in Western Canada for circum-neutral soil in bareroot nurseries.

Nitrate fertilizers, excluding ammonium nitrate, are not acid forming but could raise soil pH. Use of nitrates of sodium, potassium and calcium may result in alkaline conditions; mobile nitrate ions are readily absorbed by plan leaving an excess of basic cations.

Phosphurus: Function in Plants

Phosphorus is absorbed in lower amounts tha either N or K, but it is essential for the initiation of primordial growth and seed formation an the stimulation of root growth. It acts as an energy carrier, being part of the high energy phosphate bonds that are essential in the proces es of photosynthesis and respiration (Tisdale an Nelson 1966). Phosphorus deficiency leads to severe stunting, and depending on the plant species, leaves could be deep green or the lower (older) leaves and needles may become deeply bronzed or reddish-purple. Sometimes there are no symptoms of P deficiency besides severe reduction in growth. It is a mobile element in plant and normally deficiency symptoms develop earlies on lower (older) tissue.

Fate of Phosphorus in Soil

Availability of P in soil depends on pH and on the presence of other ions, but efficiency of P utilization by plants is low (20%). Plants absorb P mostly as orthophosphate ions, H_2PO_4 and HPO_4^{2-}. In acid medium, $H_2PO_4^-$ is favore but the presence of aluminum, iron and manganese in very acid soil results in fixation or precipitation of P as insoluble phosphates. As soil pH rises above pH 5.0, $H_2PO_4^-$ declines in favor of HPO_4^{2-} but above pH 7.0, the presence of calcium and magnesium will result in precipitation of insoluble phosphates (Tisdale and Nelson 1966). In general, soil pH of 5.0 - 6.0 is ideal for conifers whereas pH of 6.0 - 7.0 is preferable for hardwoods.

The above fixation or loss in availability may be minimized by proper placement. Broadcast

ıcement followed by intimate mixing with the
l1 leads to increased fixation, assuming the
ove factors (pH, metal ions) are present. The
commended alternative is band placement whereby
e fertilizer is set in localized bands beside
d below the seed.

Soil-fertilizer contact may be minimized
so by pelleting or aggregating the fertilizer.
is is advisable with materials of high water
lubility. (Slow-release fertilizers are coated
th slowly soluble compounds to retard reaction
the fertilizers with soil water.) This is
pecially useful in areas of high precipitation).
hanced utilization of phosphate fertilizers may
achieved also by combining them with organic
tter (peat, farm manure, etc.) to extend their
ailability.

tassium: Function in Plants

Potassium unlike N and P is not synthesized
to other compounds. It is absorbed as the ion
and is essential for protein synthesis and
production and translocation of carbohydrates.
is related to N metabolism; K deficient plants
e high in soluble N suggesting blockage in the
nthesis of protein from amino acids (Tisdale
d Nelson 1966). It is a mobile element; defi-
ncy symptoms occur first on lower leaves as
rginal or tip burn and in some cases as
lorosis. It also functions in the promotion of
owth of meristematic tissue, strengthens cell
lls and is essential to stomatal movement and
ntrol of turgor (Tisdale and Nelson 1966).

te of Potassium in Soil

Potassium in soil exists primarily as an un-
ailable (fixed) form that is in equilibrium with
aller amounts of a slowly available and readily
ailable forms. As plants absorb readily avail-
le (i.e. water soluble and exchangeable) K, the
ount absorbed is replaced from both the slowly
ailable and unavailable forms in a reversible
ocess and a dynamic equilibrium is maintained.
st (90-98%) of the K in soils is in the unavail-
le form and held by secondary clay minerals
xpanding type).

When K fertilizers are applied to the soil,
e element may be readily absorbed from solution,
absorbed by clays as exchangeable K. Some of
e unused K reverts to the slowly available form
d finally supplements the large unavailable
ol. Plant uptake causes K to move slowly in
e opposite direction and replenish the easily
ailable fraction.

Potassium is subject to leaching in soil but
s retention in slowly available and unavailable
rms for eventual release to plants helps to
nimize losses. Long term application of K
rtilizers reduces the K-fixing power of the soil
d increases the easily available (exchangeable)
action. The degree of retention against leach-
g loss will depend on soil texture and, consequently, the exchange capacity. Many bareroot nurseries have coarse textured soils with low exchange capacity and are irrigated; such soils are more prone to leaching losses of K. Leaching loss of K increases as soil acidity increases (Krause 1965) and below pH 5.0, it is advisable to apply lime to increase the degree of base saturation and lower the risk of K loss. On neutral and alkaline nursery soils in Saskatchewan leaching loss of K was miniscule compared to that of calcium, magnesium, and NO_3-N (Edwards 1977).

Timing and Placement of Fertilizers

Efficiency of utilization of fertilizers can be increased by proper timing and placement. For production of conifer seedlings in bareroot nurseries, P and K are applied as basal dressings during preparation of the seedbed prior to seeding whereas N is applied as a top dressing in multiple doses and at two to three week intervals throughout the growing season. Nitrogen fertilizers especially NO_3 are subject to leaching loss in coarse textured soil and may cause salt injury to young seedlings. Following application, all fertilizer material should be brushed off the foliage and watered lightly into the soil. Multiple applications of N are warranted also because rate of growth and nutrient uptake vary through the season (Armson 1963). A more precise approach to multiple dosage is application of the fertilizer according to the accumulation of heat units. Armson (1962) recommended the use of 36°F (2°C) as the base temperature for white spruce in Ontario.

Although many nurseries use broadcast application of P, ideal placement is banding because of its relative immobility in soil, propensity for fixation and its low degree of recovery by plants. Banding of the fertilizer (beside and below the seed) causes less mixing with the soil and lowers the risk of fixation (Tisdale and Nelson 1966). The practice requires specialized equipment and this may account for its unpopularity in tree nurseries so far. (The technique has been applied successfully in agriculture.)

Potassium is mobile in soil and may be applied as multiple top dressings. The practice is followed in some nurseries but the primary drawback is the risk of foliar burn to seedlings. Broadcast application followed by disking prior to seeding is the practice at many nurseries in the prairie region. However in locations with soils of high K-fixing capacity, band placement is advisable.

Both N and K fertilizers lend themselves to liquid application (fertigation) because of their high solubility. The practice has been followed in only one of the prairie nurseries. Degree of nutrient availability is similar compared to solid application but more practical questions have to be considered by the nurserymen. Is soil texture very coarse? Is frequent irrigation between fertilization events required because of hot weather? What is the strategy to be followed during extensive periods of rainy weather when the fields are due to be fertilized? A safe approach is to rely on solid material to supply the basic amount of nutrients. Supplemental amounts may then be supplied by liquid application. The effect of the latter may not be prolonged but it is useful as a quick boost where this is necessary, e.g. inclement weather.

Fertilizers Commonly Used in Nurseries

In bareroot nurseries, the most commonly used sources of N exclusively are ammonium sulfate (21-0-0) and ammonium nitrate (34-0-0). Phosphorus exclusively is supplied by ordinary superphosphate (0-20-0) and concentrated (triple) superphosphate (0-45-0). Popular combinations of N and P are the ammonium phosphates, specifically monoammonium phosphate (11-48-0 and 11-55-0), diammonium pnosphate (21-54-0), and ammonium phosphate-sulfate (16-20-0). The most common sources of K are potassium sulfate (0-0-50) and potassium chloride (0-0-62).

Rationale for the use of specific fertilizers is developed with biology and economics in mind and, depending on the circumstances, there may be trade-offs between both areas. Thus a price list (Table 1) may be important but long term viability of the nursery is of greater consequence. As a N source, ammonium nitrate is less acid than where soil pH is within acceptable limits. Ammonium sulfate is useful as an acidifying agent (along with elemental sulphur) where soil pH exceeds acceptable limits.

The ammonium phosphates by combining two elements help to lower handling and shpping costs per unit of nutrient. The high nutrient concentration of compounds such as diammonium phosphate adds to their attractiveness. The superphosphates are neutral (to soil pH) and the high P concentration adds to handling efficiency. The drawback with concentrated superphosphate is its uncertain availability and like other phosphate products (in Western Canada) is expensive (Table 1). Among phosphate sources monoammonium phosphate (11-55-0) was shown to be most effective for Douglas-fir (van den Driessche 1984). Monoammonium phosphate (11-48-0) was also found to be effective for white spruce (Edwards 1981).

The choice of potassium source should be governed by the prevailing salinity level in the soil and irrigation water and the ease with which the soil can be leached. Normally, in western Canadian nurseries if electrical conductivity of the soil exceeds 1.0 mS/cm and that of irrigation water exceeds 0.75 mS/cm, potassium sulfate is preferred. Potassium chloride has a greater salt index and therefore a greater potential for salinity problems and chloride toxicity.

Table 1: Cost (Can.$)[1] of selected fertilizers in western Canada in 1985

Formulation	Fertilizer[2] $/tonne	N $/kg	P $/kg	K $/kg
21-0-0	217	1.03	---	---
34-0-0	263	0.77	---	---
46-0-0	300	0.65	---	---
11-51-0	425	3.86	1.89	---
16-20-0	318	1.99	3.61	---
0-20-0	390	---	4.43	---
0-45-0	600	---	3.03	---
0-0-50	356	---	---	0.86
0-0-62	175	---	---	0.34

[1] Canadian $1.00 is equivalent to U.S. $0.70 approximately

[2] Includes transportation charges and represent random sampling over three prairie provinces.

SUMMARY

The major elements N, P and K are essentia to proper plant growth and play a most importan role in the constitution of chemical fertilizer that are commonly applied in tree nurseries. I order to use the fertilizers most efficiently, i is necessary to know how each element reacts wi the soil following application and the factors that affect their uptake by plants. These considerations will determine optimum timing and placement of the fertilizer. Cost and availabi-ty of fertilizers affect selection of specific materials but biological concerns ought to be given priority.

LITERATURE CITED

Armson, K. A. 1962. The growth of white spruce seedlings in relation to temperature summation indices. For. Chron. 38:439-444.

Armson, K. A. 1965. Seasonal patterns of nutrie absorption by forest trees. p. 65-75. In Forest Soil Relationships in North America, C. T. Youngberg Ed. Papers presented at the Second North American Forest Soils Conference, Oregon State University, Corvallis, C August 1963. 532 p.

lwards, I. K. 1977. Nutrient movement in a sandy loam forest nursery soil at Prince Albert, Saskatchewan. Can. For. Serv., Nor. For. Res. Cent., Inf. Rep. NOR-X-195.

lwards, I. K. 1981. Soil amendments and fertilizers improve bareroot seedling growth in tree nurseries. p. 7-10. In Forestry Report. J. Waldron and J. Samoil editors. Can. For. Serv., Nor. For. Res. Cent. For. Rep. No. 24. Edmonton, Alberta 16 p.

Krause, H. H. 1965. Effect of pH on leaching losses of potassium applied to forest nursery soils. Soil Sci. Soc. Am. Proc. 29: 613-615.

Tisdale, S. L. and W. L. Nelson. 1966. Soil fertility and fertilizers. Second edition. 694 p. Macmillan Company, New York.

van den Driessche, R. 1984. Response of Douglas-fir seedlings to phsophorus fertilization and influence of temperature on this response. Plant and Soil 80:155-169.

Cold-Hardiness Testing of Conifer Seedlings[1]

Karen E. Burr, Stephen J. Wallner, and Richard W. Tinus[2]

Abstract.--This paper briefly describes the results of preliminary experiments designed to test four objective methods of rapidly predicting cold hardiness of conifer seedlings; differential thermal analysis, ethylene evolution, and freeze-induced and heat-induced electrolyte leakage.

INTRODUCTION

We are testing four objective methods of rapidly predicting cold hardiness of conifer seedlings; differential thermal analysis, ethylene evolution, and freeze-induced and heat-induced electrolyte leakage. This information will be used as a research tool to optimize hardening regimes and as a management tool to reduce losses associated with the timing of removal of seedlings from the greenhouse, cold storage, and outplanting.

DIFFERENTIAL THERMAL ANALYSIS (DTA)

DTA of buds is one approach for those species that supercool, such as the spruces and Douglas-fir. The cold hardiness of these species is related to their capacity for supercooling, and the extent of that supercooling is measured by DTA.

The DTA profile of a cold hardy bud that supercools (fig. 1) has two peaks or exotherms which are formed when heat is released by the freezing of water within the bud. The first exotherm represents freezing of extracellular water which generally causes no injury to the bud. The low temperature exotherm (LTE) represents freezing of supercooled intracellular water and is associated with lethal injury (Sakai 1978). The DTA profile of a cold hardy bud from a species that does not supercool, such as any of the pines, has a first exotherm but no LTE and is thus of no diagnostic value. The temperatures at which LTE's occur in buds that supercool are well correlated with bud acclimation and deacclimation to cold (fig. 2) and with concurrent changes in whole pl condition (fig. 3).

Concerns about bud sampling for DTA are eas by the relatively low variability of LTE temperatures among buds of individual cold hardy trees (figs. 4 and 5). However, extremely small buds not provide reliable DTA data (fig. 6). Minimum fresh weight guidelines were set at 2.8 mg for Douglas-fir buds and 1.2 mg for Engelmann spruce buds. Position on the tree had no significant effect on LTE temperature for buds of adequate s on fully cold hardy trees.

Three other approaches for predicting cold hardiness are under consideration, since pines d not supercool and buds are not always present on those species that do.

ETHYLENE EVOLUTION

A seasonal pattern of ethylene production h been observed in white pine (Seibel and Fuchigam 1978). Ethylene levels were highest in spring

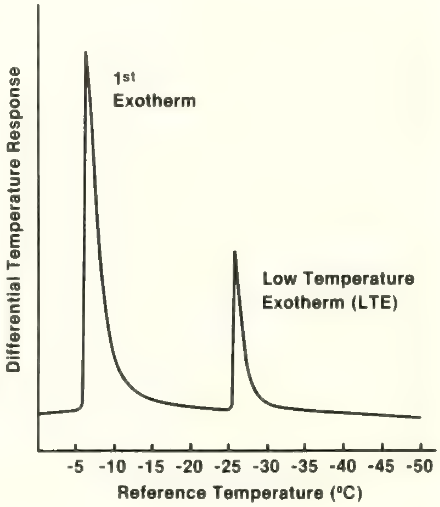

Figure 1.--DTA profile of a cold hardy bud that supercools.

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[1] Poster presented at the Intermountain Nurseryman's Association Meeting. [Fort Collins, Colo., August 13-15, 1985].

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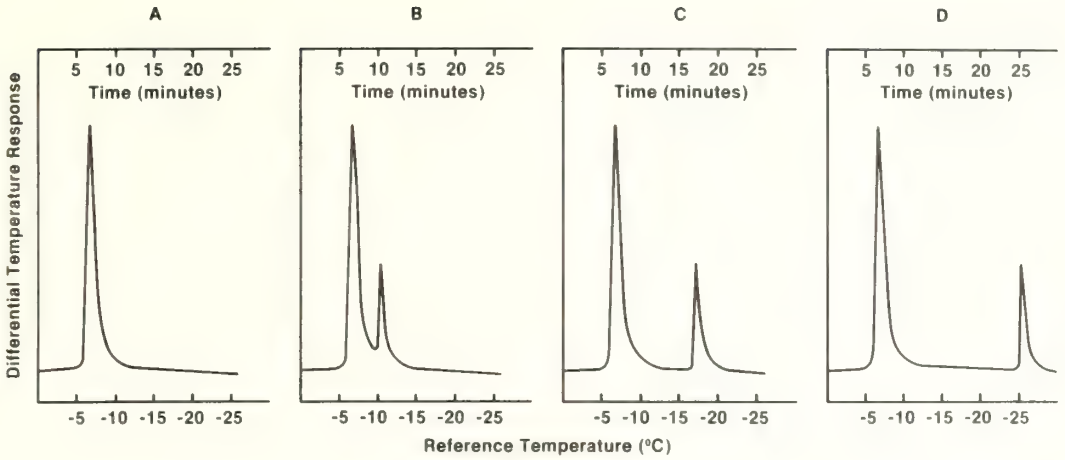

Figure 2.--Acclimation of buds that supercool, as indicated by LTE temperature. The reverse occurs with deacclimation. A. Non-acclimated. The single exotherm represents freezing of all tissue water which results in injury. B. Early acclimation. The capacity for supercooling has developed. C. Moderately cold hardy. LTE temperatures become progressively lower with increasing cold hardiness. D. Fully cold hardy. Bud LTE's at -25° C commonly occur in fully cold hardy Engelmann spruce grown in Colorado.

ring active growth, declined to low levels in
ll with vegetative maturity, and were not
tectable during winter. Preliminary investiga-
on using gas chromatography suggests this
pattern may also exist in ponderosa pine, but it is not likely to occur in Douglas-fir or Engelmann spruce (fig. 7).

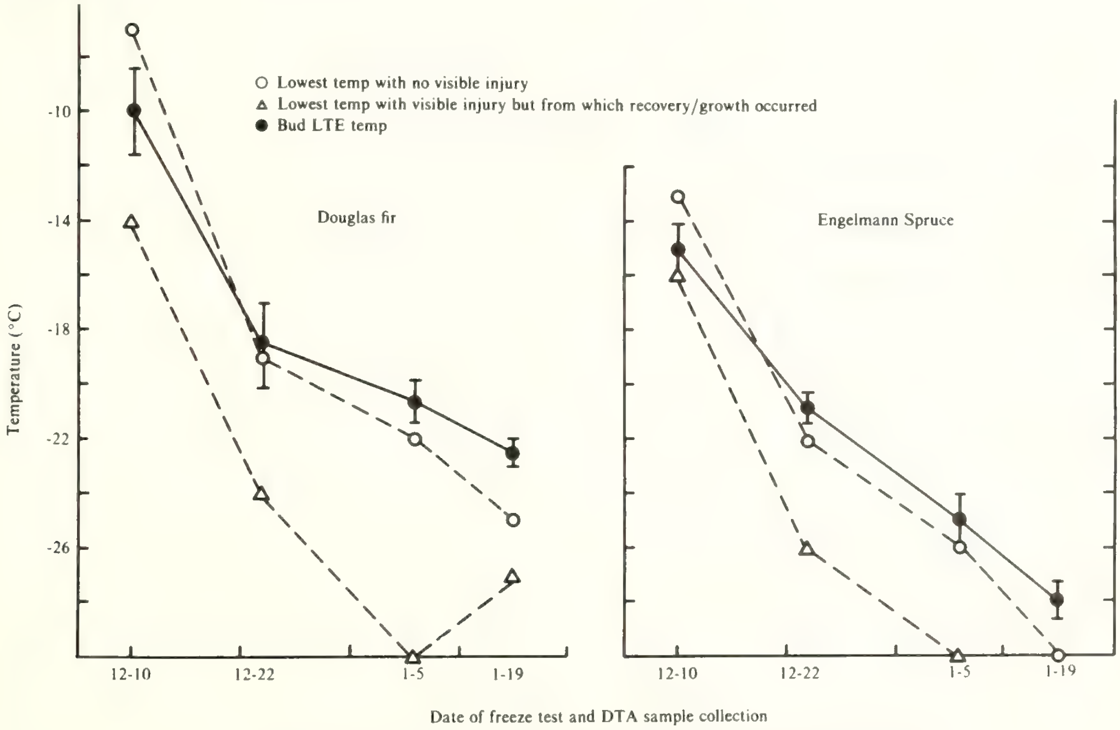

Figure 3.--Comparison of bud LTE temperatures and the results of whole plant freezing tests (Tinus et al. 1985).

ELECTROLYTE LEAKAGE

Plant hardiness with respect to temperature stresses which, when injurious, cause disruption of cell membranes and the subsequent leakage of cell contents, can be quantified by measuring the amount of electrolytes which leak from the plant tissue following exposure to a given stress. Electrolyte leakage is reported as percent index of injury, calculated by the formula

$$1 - \frac{1-(T_1/T_2)}{1-(C_1/C_2)} \times 100$$

where T_1 and T_2 are the conductivity of the treatment solution before and after boiling, respectively, and C_1 and C_2 are the conductivity of the control solution before and after boiling, respectively (Flint et al. 1967). A lower percent index of injury indicates greater hardiness.

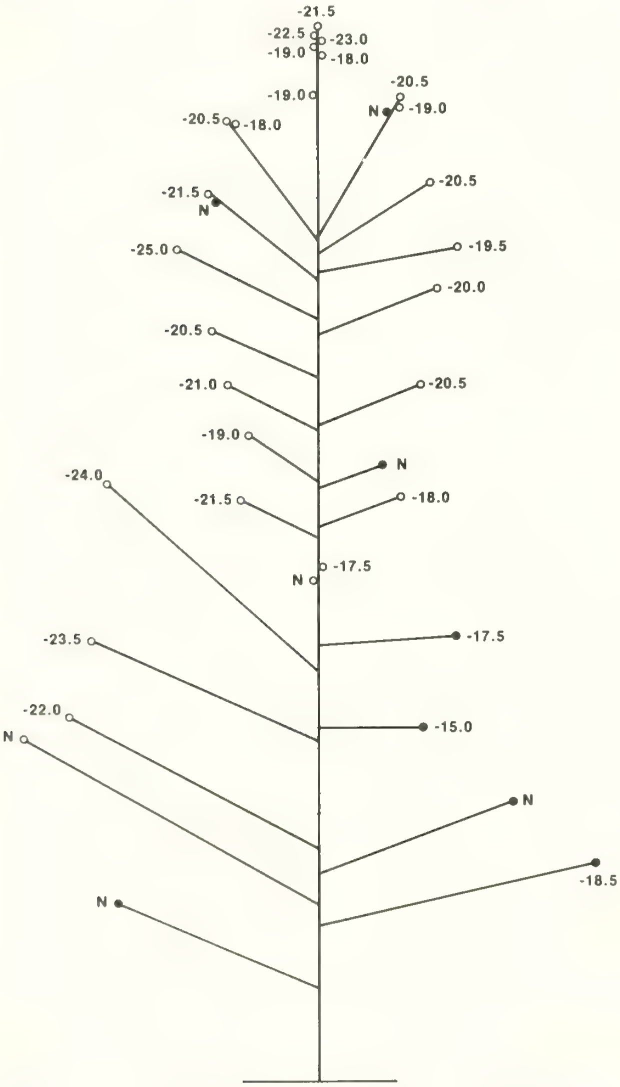

Figure 4.--Scale drawing of a fully cold hardy, 2-year-old, container grown Douglas-fir seedling 33.2 cm tall. LTE temperatures are in °C for each bud. Mean LTE temperature, ± 1 standard deviation, is -20±1.5° C. 'N' indicates no reliable LTE detected.

- ● Bud fresh weight <2.8 mg
- o Bud fresh weight ≥2.8 mg

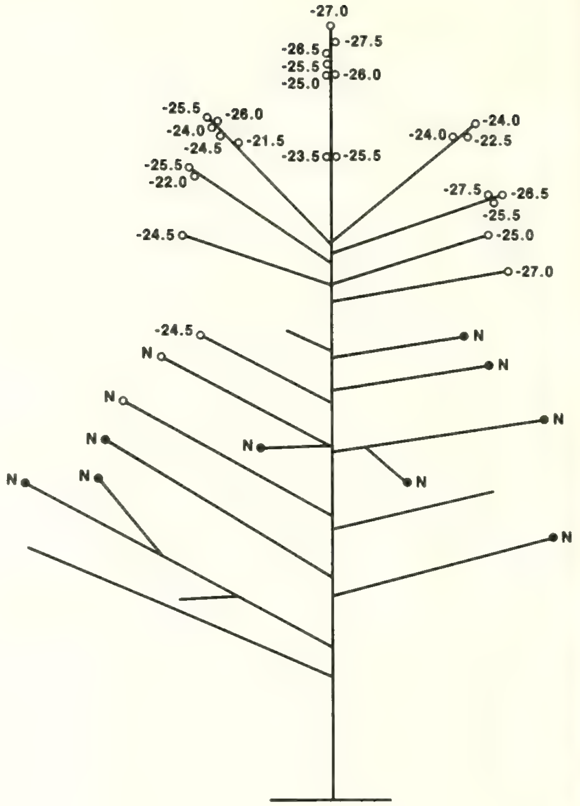

Figure 5.--Scale drawing of a fully cold hardy, 2-year-old, container grown Engelmann spruc seedling 24.5 cm tall. LTE temperatures ar in °C for each bud. Mean LTE temperature, ± 1 standard deviation, is -25±2.8° C. 'N' indicates no reliable LTE detected.

- ● Bud fresh weight <1.2 mg
- o Bud fresh weight ≥1.2 mg

Freeze Induced

Electrolyte leakage from Douglas-fir needle tissue following in vitro freezing stress was measured on samples taken at 16 intervals throug out a 152-day, growth chamber controlled, cold hardening and deacclimation regime to produce th series of curves in figure 8. Seven test temper tures were selected at each interval to produce each individual curve. Precise testing procedur enable the detection of fairly small changes in cold hardiness over time. Similar series of cur have been produced for ponderosa pine and Engelm spruce.

Heat Induced

The changes which confer cold hardiness als result in greater heat tolerance for certain species (Levitt 1980). Electrolyte leakage from needle tissue following in vitro heat stress was measured to assess the possibility of this occurring in conifers. Results for ponderosa pine we opposite those for Douglas-fir and Engelmann spr (fig. 9).

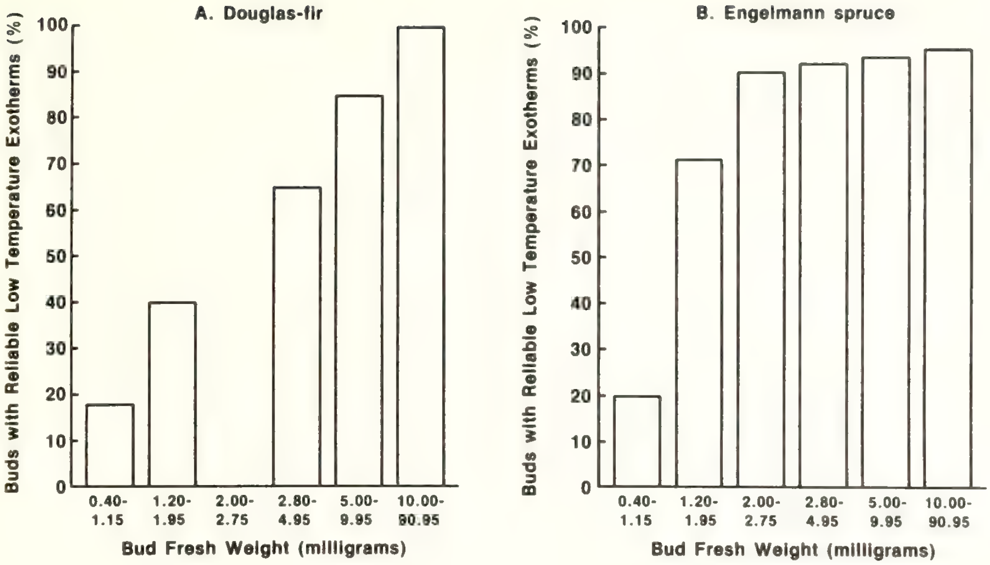

Figure 6.--Percentage of buds from cold hardy seedlings with reliable LTE's by bud fresh weight.

FUTURE RESEARCH

Extensive whole plant freezing tests are being
nducted to calibrate each of the four quick
ssue tests and to determine how well these tests
edict cold hardiness. These results are also
ing compared with measurements of dormancy and
ot growth capacity.

LITERATURE CITED

int, H. L., B. R. Boyce, and D. J. Beattie. 1967. Index of injury--A useful expression of freezing injury to plant tissues as determined by the electrolytic method. Canadian Journal of Plant Science 47:229-230.

Levitt, J. 1980. Responses of plants to environmental stresses. Volume 1. Chilling, freezing and high temperature stresses. Academic Press, N.Y.

Sakai, A. 1978. Low temperature exotherms of winter buds of hardy conifers. Plant and Cell Physiology 19:1439-1446.

Seibel, J., and L. Fuchigami. 1978. Ethylene production as an indicator of seasonal development in red-osier dogwood. Journal of the American Society for Horticultural Science 103(6):739-741.

Tinus, R. W., J. E. Bourque, and S. J. Wallner. 1985. Estimation of cold hardiness of Douglas-fir and Engelmann spruce seedlings by differential thermal analysis of buds. Annals of Applied Biology 106:393-397.

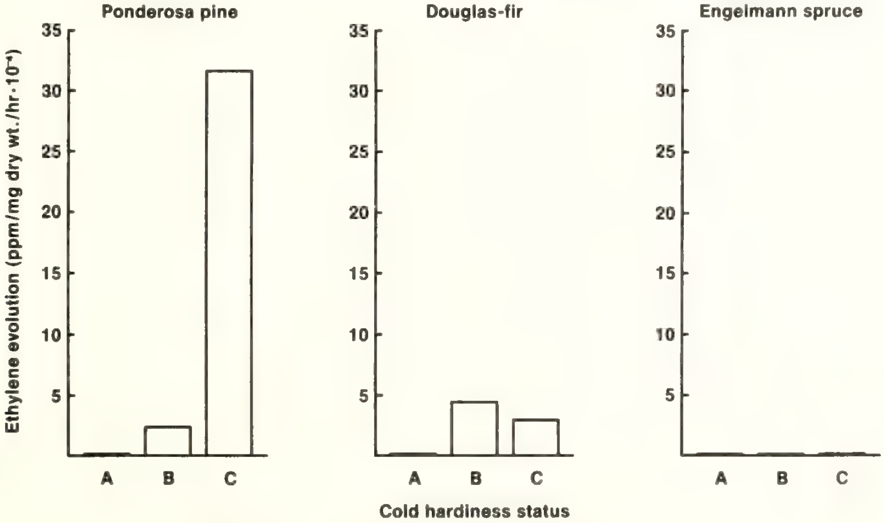

Figure 7.--Ethylene evolution from needle samples of three species at varying levels of cold hardiness:
(A) fully cold hardy, (B) early cold deacclimation,
(C) actively growing.

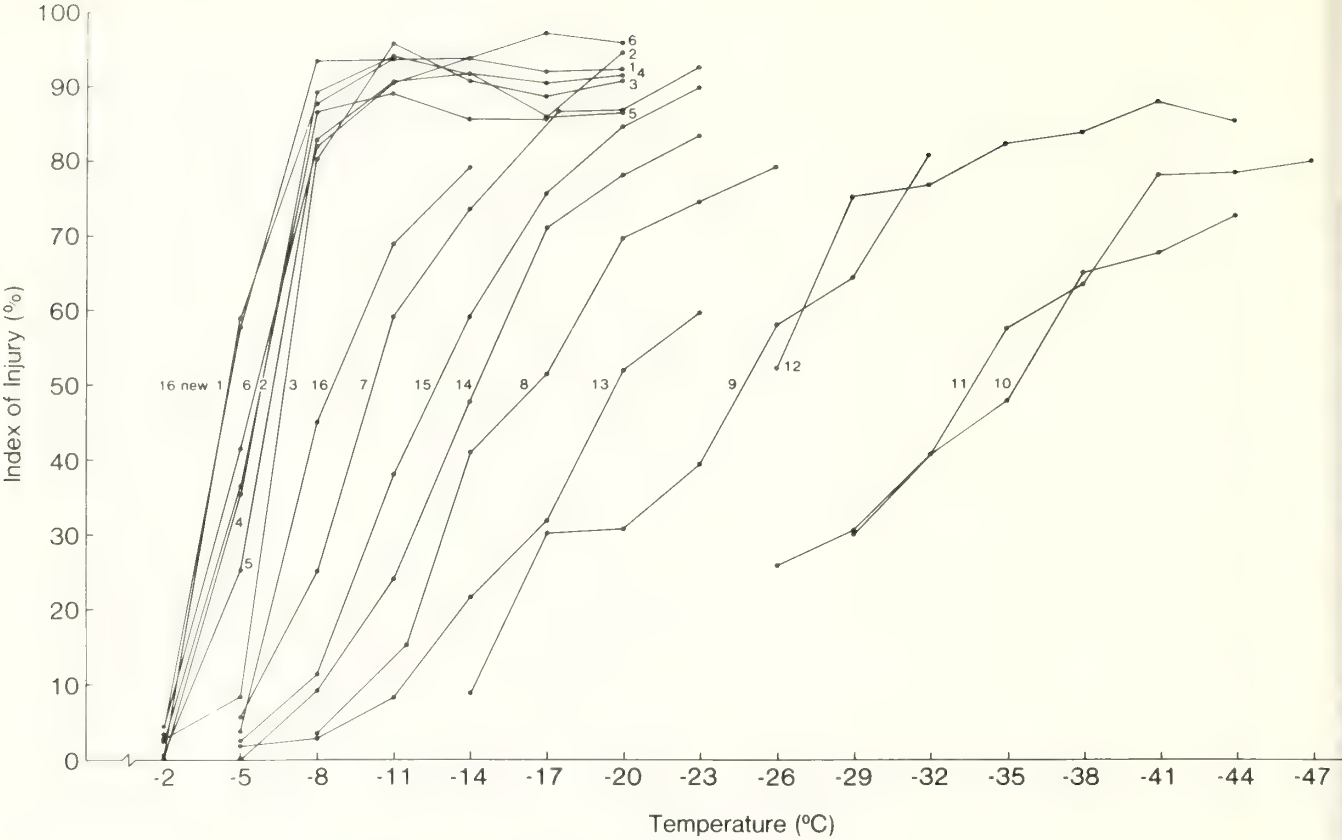

Figure 8.--Index of injury following in vitro freezing stress of Douglas-fir needles sampled at intervals throughout a cold hardening and deacclimating regime. The hardening portion of the regime began with actively growing seedlings represented by curve 1 and ended 111 days later with fully cold hardy seedlings represented by curve 11. The deacclimation period began on the 112th day and includes curves 12 through 16. The previous season's growth and the new growth were both tested on the completely deacclimated, actively growing seedlings on the 152nd day and are represented by curves 16 and 16 new, respectively.

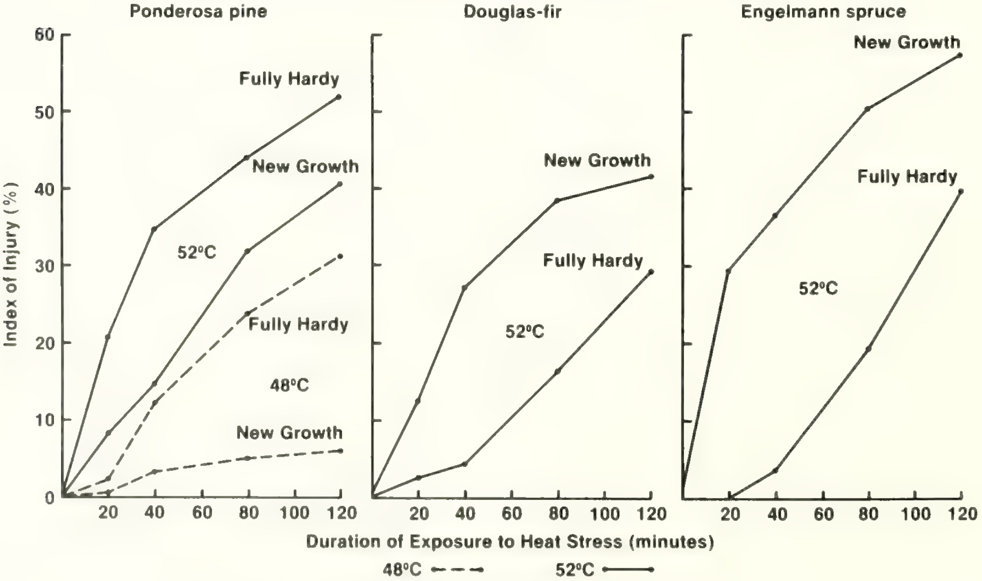

Figure 9.--Index of injury following in vitro heat stress of needle samples from actively growing and fully cold hardy seedlings of three species.

Business Meeting Notes

ERE: Lyons Park, Lyons, Colorado

EN: August 14, 1985

Chairman, Marvin Strachan, called meeting order at 1:15 p.m.

D BUSINESS:

Sally Johnson reported on progress for 1986 int meeting with Western Forest Nursery Council be held in Olympia, WA. Sally said "They're rking on it!"

Al Myatt said plans for the 1987 Intermoun- in meeting are proceeding. It will be held Norman, OK, and he solicited ideas for "a new ist" to the meeting. Submit your ideas in iting to Al at the Oklahoma State Nursery.

Tom Landis reported that the Proceedings om last year's meeting in Coeur d'Alene, Idaho, s out as a General Technical Report and cost 000 to publish. Tom doesn't know how much nger the publication money will be available om the Forest Service. He said this year's oceedings will be covered in the same manner. tions for future publication, if and when the ney is no longer available through the Forest ervice, include: 1) Special Edition of "Tree lanter Notes." 2) Publish through the "Canadian urnal of Forest Research."

EW BUSINESS:

Dave Simpson made a bid for 1988 joint eeting to be held in British Columbia. David rierson offered, in the name of Utah State Lands Forestry, to host the 1989 meeting in Utah. ffer seconded by Frank Rothe and accepted by a ajority voice vote.

Randy Selig made a motion to change the ame of our Association from "Intermountain urserymen's Association" to "Intermountain Nurs- ry Association." Motion was seconded by Tom andis. Motion carried on a majority voice vote.

NFORMATIONAL NOTES:

Dick Jeffers announced his investigation f the idea to create a Nursery Working Group as part of the Forestry Committee of the Great lains Agricultural Council. This working group ould pursue nursery related research problems or the Great Plains Area. The working group ould meet annually in conjunction with the Forestry Committee meeting. He will be soliciting nput from us in the future.

Lee Hinds announced the International Windbreak Symposium to be held in Lincoln, Nebraska, on June 23-27, 1986. Volunteer papers are being called for and a text book (manual) for windbreak establishment and care will result from this meeting.

Jerry Grebasch made a plea for more east-west exchange of information. He expressed his appreciation for being invited to our meeting and suggested we might consider sending the Chairperson of our annual meeting to the eastern meeting as a representative of INA. No action was taken.

Lee Hinds moved to adjourn the meeting. Sally Johnson seconded. Meeting adjourned at 1:55 p.m.

Respectfully submitted by:

Jim Fischer
for the Intermountain Nursery Association.

MESSAGE AND ACKNOWLEDGEMENT FROM CHAIRPERSON

The 85 registered participants found the 25th annual meeting of the Intermountain Nursery Association not only informative but also enjoyable. Several concepts, new to the Intermountain Nursery Group, proved to be successful. The membership convened in four concurrent groups to discuss high priority topics. Each group was able to attend and participate in all four sessions. Twelve prepared papers were well presented at the formal paper session.

The tour not only observed Forest Nursery operations but also ecological conditions in the Rocky Mountain National Park area.

Special acknowledgement must be given to the commercial exhibitors who contributed financial assistance and demonstrated their products and information to the forest nurserymen. These contributors were Native Plants, Inc., Stuewe & Sons, Loveland Industries, Silva Seed, American Clayworks and the J. E. Love Company. Much credit for a successful meeting must also go to the membership who contributed much by demonstrating a high degree of interest and cooperation. We thank you all.

Marvin D. Strachan
Chairman

List of Attendees

Larry Abrahamson
State University of New York
Syracuse, New York

Lyle Alspach
PFRA Tree Nursery
Agriculture Canada
Indian Head, Saskatchewan, Canada

Amanullah K. Arbab
Tribal Forestry Department
Fort Defiance, Arizona

Jim Barnett
U.S. Forest Service
Pineville, Louisiana

Jim Borland
Denver Botanical Gardens
Denver, Colorado

Karen E. Burr
Department of Horticulture
Colorado State University
Fort Collins, Colorado

Peter Clarkson
Technical Forestry Services
Portage La Prairie, Manitoba, Canada

Tom Corse
Bureau of Indian Affairs
Polson, Montana 59860

Rodger Danielson
Oregon State University
Corvallis, Oregon

Robyn Darbyshire
Oregon State University
Corvallis, Oregon

Al deHaas
USFS, Placerville Nursery
Camino, California

Gary Dinkel
USFS, Bessey Nursery
Halsey, Nebraska

Ivor Edwards
Canadian Forestry Service
Edmonton, Alberta, Canada

Kent L. Eggleston
USFS North Central Experiment Station
Rhinelander, Wisconsin

Thomas P. Emerson
USFS
Watersmeet, Michigan

Jay Faulconer
International Paper Co.
Lebanon, Oregon

Robert J. Fewin
Texas Forest Service
Lubbock, Texas

Jim Fischer
Colorado State Forest Service
Colorado State University
Fort Collins, Colorado

Mike Gerdes
Silvaseed

Robby Gibson
Colorado State Forest Service
CSU
Fort Collins, Colorado

John Gleason
Oregon State University
Corvallis, Oregon

Jerry Grebasch
Iowa Conservation Commission
Ames, Iowa

David Grierson
Utah State Lands & Forestry
Draper, Utah

Allen C. Hackleman
CSFS, CSU
Fort Collins, Colorado

Oscar Hall
USDA Forest Service
National Tree Seed Laboratory
Dry Branch, Georgia

Roger Hamilton
Alberta Forest Service
Smoky Lake, Alta, Canada

Jill E. Handwerk
Greener 'n Ever Tree Farm
Fort Collins, Colorado

Gene Hartzell
California Department of Forestry
Davis, California

Eileen Harvey
Canadian Forestry Service
Edmonton, Alberta, Canada

Mark Harvey
Alberta Forest Service
Edmonton, Alberta, Canada

Willis J. Heron
Dept. of State Lands
Division of Forestry
Missoula, Montana

Rex Huffacre
Native Plants, Inc.

Lee Hinds
Lincoln-Oakes Nurseries
Bismarck, North Dakota

John H. Hinz
USFS Bessey Nursery
Halsey, Nebraska

Richard M. Jeffers
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Lakewood, Colorado

Sally Johnson
Seedling Quality Services
Centralia, Washington

James (Jeff) Kayler
Fantasy Farm NSY
Peck, Idaho

Mark Kettler
Technical Forestry Services
Portage La Prairie, Manitoba, C

Glen Killough
Texas Forest Service
Lubbock, Texas

Roy Laframboise
North Dakota Forest Service
Towner, North Dakota

Tom D. Landis
USDA Forest Service
Lakewood, Colorado

Matt Lavin
University of Texas
Austin, Texas

C.D. McAninch
USDA Forest Service
Lakewood, Colorado

Doug McCreary
Oregon State University
Corvallis, Oregon

Fred McElroy
Peninsu-Lab
Kingston, Washington

l McKinley
eener 'n Ever Tree Farm
mel, California

icy K. McQuinn
ipson Timber Co.
ata, California

icy Mikkelson
orado State University
t Collins, Colorado

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Div. of Forestry
Sioux Nursery
ertown, South Dakota

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shington, Oklahoma

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veland Industries/Hopkins
dison, Wisconsin

e Perry
eener 'n Ever Tree Farm
rmel, California

air Posey
VA Nursery
rkdale, Oregon

Tony Ramirez
Lone Peak State Nursery
Draper, Utah

Verna Reedy
Champion Timberlands Nursery
Plains, Montana

Bob Reeves
Loveland Industries, Inc.
Loveland, Colorado

Larry Roberts
CSFS, CSU
Fort Collins, Colorado

Ed Rothe
Colo-Hydro, Inc.
Longmont, Colorado

Frank Rothe
Colo-Hydro, Inc.
Longmont, Colorado

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Arcata, California

Richard M. Schaefer
Potlatch Corporation
Lewiston, Idaho

Bill Scheuner
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Camino, California

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David L. Wenny
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Moscow, Idaho

Leaford Windle
USDA Albuquerque Nursery
Belen, New Mexico

Barry Wood
Pine Ridge Forest Nursery
Smoky Lake, Alta, Canada

Terry S. Yeh
USFS Cibola National Forest
Peralta, New Mexico

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

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Silvicultural Systems and Cutting Methods for Old-Growth Spruce-Fir Forests in the Central and Southern Rocky Mountains

Robert R. Alexander

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Abstract

Guidelines are provided to help the forest manager and silviculturist develop even- and/or uneven-aged cutting practices needed to convert old-growth spruce-fir forests into managed stands for a variety of resource needs. Guidelines consider stand conditions, succession, windfall risk, and insect and disease susceptibility. Cutting practices are designed to integrate timber production with increased water yield, maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing.

Cover Photo.—Old-growth spruce-fir forests, Fraser Experimental Forest, Colorado.

SDA Forest Service
eneral Technical Report RM-126

April 1986

Silvicultural Systems and Cutting Methods for Old-Growth Spruce-Fir Forests in the Central and Southern Rocky Mountains

Robert R. Alexander, Chief Silviculturist
Rocky Mountain Forest and Range Experiment Station[1]

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[1] *Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Contents

Page

NATURAL STANDS 1
  AGE-CLASS DISTRIBUTION 1
  REACTION TO COMPETITION AND DISTURBANCE 1
  STAND CONDITIONS 2
DAMAGING AGENTS 2
  WIND 2
  INSECTS 3
  DISEASES 4
  FIRE 5
  ANIMALS 5
CUTTING HISTORY 5
REGENERATION SILVICULTURAL SYSTEMS 7
  EVEN-AGED CUTTING METHODS 7
    Management with Advanced Regeneration 7
      Simulated Shelterwood Cutting 7
    Management for Regeneration After Cutting 8
      Clearcutting 8
      Shelterwood Cutting 11
  UNEVEN-AGED CUTTING METHODS 18
    Individual Tree Selection Cutting 18
    Group Selection Cutting 18
    Stand Structure Goals 18
      Control of Stocking 18
      Maximum Tree Size 19
      Control of Diameter Distribution 19
    How to Determine Residual Stand Structure 20
    How to Handle Small Trees 22
    Marking Trees 23
    Recommendations for Selection Cutting 25
      Stand Structure Goals, Cutting Treaments, and Reentry Schedules 25
    Protecting the Residual Stand 25
COSTS OF SALE ADMINISTRATION AND LOGGING 25
MULTIPLE-USE SILVICULTURE 26
  SOIL AND WATER RESOURCES 26
    Water Yield 26
    Soil Erosion and Water Quality 27
    Nutrient Losses and Stream Water Temperature Changes 27
  WILDLIFE AND RANGE RESOURCES 27
    Game Habitat 27
    Nongame Habitat 28
    Livestock Grazing 28
  RECREATION AND ESTHETICS 28
  COMPARISON OF CUTTING METHODS 29
LITERATURE CITED 30

Silvicultural Systems and Cutting Methods for Old-Growth Spruce-Fir Forests in the Central and Southern Rocky Mountains

Robert R. Alexander

Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)—subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forests (SAF Type 206) (Alexander 1980, Society of American Foresters 1980) are the predominant multiple-use forests in the central and southern Rocky Mountains. These forests occupy about 4.2 million acres of timberland with an estimated 47 billion board feet (INT 1/4 Rule) of sawtimber (Green and Van Hooser 1983). They grow on areas of moderate to high timber production potential. These forests also occupy the highest potential water yielding areas and provide habitats for a variety of wildlife, forage for livestock, summer and winter dispersed and developed recreational opportunities, and outstanding scenic beauty. In addition, much other land now covered by seral tree species, such as lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and quaking aspen (*Populus tremuloides* Michx.), also has the potential to grow spruce and fir (Alexander 1977, Alexander and Engelby 1983).

NATURAL STANDS

AGE-CLASS DISTRIBUTION

Spruce-fir forests generally have an imbalance in age-class distribution. Most of the stocked area is in sawtimber, and the least is in seedling and sapling stands. The vast majority of these stands, therefore, are overmature and declining in vigor and soundness.

Only about 10% of the spruce-fir is classified as immature stands. Most of the poletimber became established after wildfires burned in the early 1900s. Because wildfires are random events and most fires burned a relatively small average area, poletimber stands of spruce-fir are scattered throughout the central and southern Rocky Mountains. About 8% of the spruce-fir forest lands are classified as seedling and sapling stands. These stands originated from either fires or cutting. Nearly 6% of timberland is classified as nonstocked. Failure of tree reproduction after fire or cutting accounts for some of the nonstocked area; but not all nonstocked lands can support commercial spruce-fir forests (Green and Van Hooser 1983).

REACTION TO COMPETITION AND DISTURBANCE

In the central and southern Rocky Mountains, Engelmann spruce is rated shade tolerant (Baker 1949). It is definitely more shade tolerant than associates such as ponderosa pine (*Pinus ponderosa* Laws), Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), lodgepole pine, quaking aspen, blue spruce (*Picea pungens* Engelm.), and southwestern white pine (*Pinus strobiformis* Engelm.); but less than its most common associate, subalpine fir, and corkbark fir (*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.) and white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.).

Engelmann spruce grows in at least 142 recognized habitat types, community types, and plant communities, and is either a co-climax with subalpine fir or a long-lived seral forest vegetation in most of them (Alexander 1985b). In the central and southern Rocky Mountains, Engelmann spruce and subalpine fir occur as either codominant mixtures or in nearly pure stands of either species. Elsewhere in the Rocky Mountains and associated ranges, subalpine fir is the major climax species. Engelmann spruce also may occur as a major climax species; but more often it is a persistent long-lived seral species. Pure stands of either species can be found throughout the Rocky Mountains, however (Alexander 1980).

Climax forests are not easily displaced by other vegetation; but fire, logging, and insects have significantly influenced the successional status and composition of spruce-fir forests. Complete removal of the stand by fire or logging results in such drastic environmental changes that spruce and fir usually are replaced by lodgepole pine, quaking aspen, or shrub and grass communities (Roe et al. 1970, Stahelin 1943, Whipple and Dix 1979). The kind of vegetation initially occupying the site usually determines the length of time it takes to return to a spruce-fir forest. It may vary from a few years, if the site is initially occupied by lodgepole pine or quaking aspen, to as many as 300 or more years if grass is the replacement community (fig. 1). Although the factors that deter-

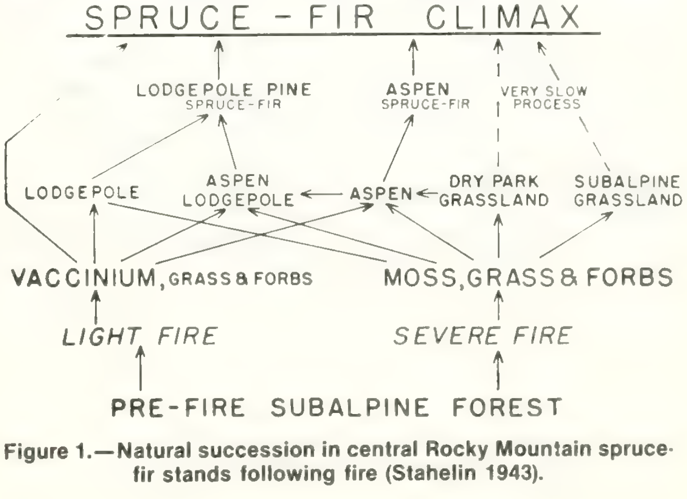


Figure 1.—Natural succession in central Rocky Mountain spruce-fir stands following fire (Stahelin 1943).

mine the kind of replacement stand are not fully understood, the nature of the disturbance and the habitat type are useful in predicting succession. Attacks by spruce beetle (*Dendroctonus rufipennis*, Kirby) usually have resulted in a change in the dominant element of the stand from spruce to fir. Because of its larger size and longer life, spruce usually regains its dominant position in the stand, only to be removed again by spruce beetles (Schmid and Frye 1977, Schmid and Hinds 1974).

STAND CONDITIONS

Old growth spruce-fir forests grow on a wide range of sites with a great diversity of stand conditions and characteristics. For example, although spruce-fir forests form climax or near-climax plant associations throughout the central and southern Rocky Mountains, they differ from most climax forests in that stands are not truly all-aged (Alexander 1985a, Hanley et al. 1975, LeBarron and Jemison 1953). Some stands are clearly single-storied, indicating that spruce forests can be grown under even-aged management. Other stands are two- or three-storied, and multistoried stands are not uncommon (Alexander 1973, Miller 1970). These may be the result of either past disturbances, such as fire, insect epidemics, or cutting, or the gradual deterioration of old-growth stands associated with normal mortality from wind, insects, and diseases. Gradual mortality is especially evident in the formation of some multistoried stands. However, some multistoried stands appear to have originated as uneven-aged stands, and are successfully perpetuating this age-class structure (Alexander 1985a, Hanley et al. 1975, Whipple and Dix 1979). Regardless of stand structure, trees may be uniformly spaced or they may grow in groups, clumps, or patches. Two or more stand conditions and/or characteristics frequently occur on the same tract.

The composition of spruce-fir forests varies considerably with elevation. At mid-elevations (10,000 to 11,000 feet), these forests are frequently pure spruce in the overstory with fir predominating in the understory. For example, in the central Rocky Mountains, spruce commonly makes up 70% or more of the overstory basal area, and fir from two-thirds to three-fourths of the understory and advanced reproduction (Alexander 1957, 1963, 1968; Hodson and Foster 1910, Oosting and Reed 1952). This composition in relation to structure has developed under natural conditions, because spruce is more exacting in its seedbed requirements and less able to compete with fir under low light intensities common to dense forests. Once established, however, spruce lives longer than fir and is less susceptible to disease (Alexander and Shepperd 1984, Alexander et al. 1984). Exceptions are stands recently attacked by spruce beetles, where fir is the dominant element in both the overstory and understory. At higher elevations in the central and southern Rocky Mountains, spruce may form essentially pure stands, while at lower elevations where sites are usually drier, the density of spruce relative to fir may be low. In these latter situations in the central Rocky Mountains, lodgepole pine, a long-lived seral species, o aspen frequently are more numerous in the overstor than spruce, especially on sites disturbed by logging o fire.

Advanced spruce and fir reproduction is likely to b older than it appears, because the early growth of bot is slow. Spruce commonly takes from 20 to 40 years t reach a height of 4 to 5 feet, even under favorable con ditions, whereas under a dense canopy, spruces 4 to feet tall may be 75 or more years old (Oosting and Ree 1952). Spruce and fir reproduction suppressed for lon periods of time will respond to release, however, and wi make acceptable growth (Alexander 1968, McCaughe and Schmidt 1982).

DAMAGING AGENTS

WIND

Windfall is a common cause of mortality after any kin of initial cuttings in mature and overmature spruce-fi forests. Low stumpage values and the generally scatter pattern of windfall may prevent the salvage of blow down. Not only is the volume of windthrown trees los but downed spruce trees provide ideal breeding ground for the spruce beetle. The high endemic populations c beetles normally associated with old-growth spruce-fi forests can multiply rapidly to epidemic proportions i the windthrown trees and then emerge to attack livin trees.

Windfall losses are heavy after any kind of partial cu ting in spruce-fir forests. Less damage is associated wit clearcutting, because only the boundaries between cu and uncut areas are vulnerable. Losses can be substa tial along the boundaries of clearcuttings, however, pa ticularly if no special effort is made to select windfir boundaries (Alexander 1964, 1967).

While the tendency of spruce and fir to windthrow i usually attributed to a shallow root system, the develo ment of the root system varies with soil and stand co ditions. On medium to deep, well-drained soils, tre have a better root system than on shallow, poorly draine soils. Trees that have developed together in dense stan over long periods of time mutually protect each othe and do not have the roots, boles, or crowns to withstan sudden exposure to wind if opened up too drasticall If the roots and boles are defective, the risk of windthro is increased. The presence of old windfalls in a stan is a good indicator of lack of windfirmness. Furthermor regardless of the kind or intensity of cutting, or soil an stand conditions, windthrow is greater on some exp sures than others (Alexander 1964, 1967, 1973). Exp sures where windfall risk is below average, abo average, or very high have been identified (fig. 2) follows.

Low

1. Valley bottoms, except where parallel to the dire tion of prevailing winds, and flat areas.
2. All lower, and gentle middle north- and eas facing slopes.

3. All lower, and gentle middle south- and west-facing slopes that are protected from the wind by considerably higher ground not far to windward.

Moderate

1. Valley bottoms parallel to the direction of prevailing winds.
2. Gentle middle south and west slopes not protected to windward.
3. Moderate to steep middle, and all upper north- and east-facing slopes.
4. Moderate to steep middle south- and west-facing slopes protected by considerably higher ground not far to windward.

High

1. Ridgetops.
2. Saddles in ridges.
3. Moderate to steep middle south- and west-facing slopes not protected to windward.
4. All upper south- and west-facing slopes.

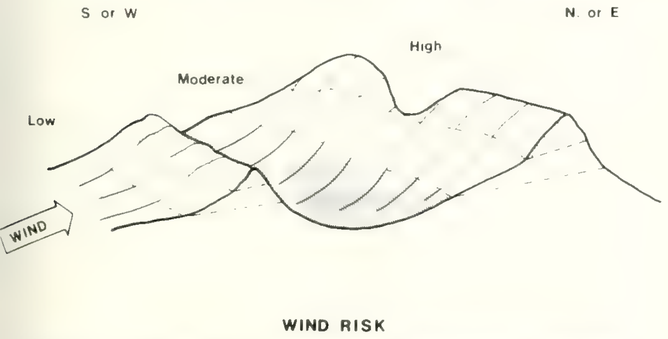
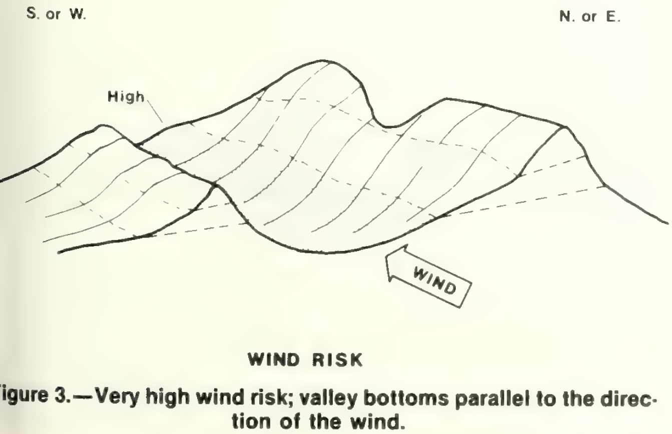


Figure 2.—Wind risk in relation to topographic exposure.

The risk of windfall in these situations is increased at east one category by factors such as poor drainage, hallow soils, defective roots and boles, and overly dense tands. Conversely, the risk of windfall is reduced if the tand is open grown or composed of young, vigorous, ound trees. All situations become very high risk if exosed to special topographic situations such as valley ottoms with steep side slopes that are parallel to the vind and become narrower in the direction of the wind fig. 3), and gaps or saddles in ridges at higher elevations o windward that can funnel winds into the area (fig. 4).



igure 3.—Very high wind risk; valley bottoms parallel to the direction of the wind.

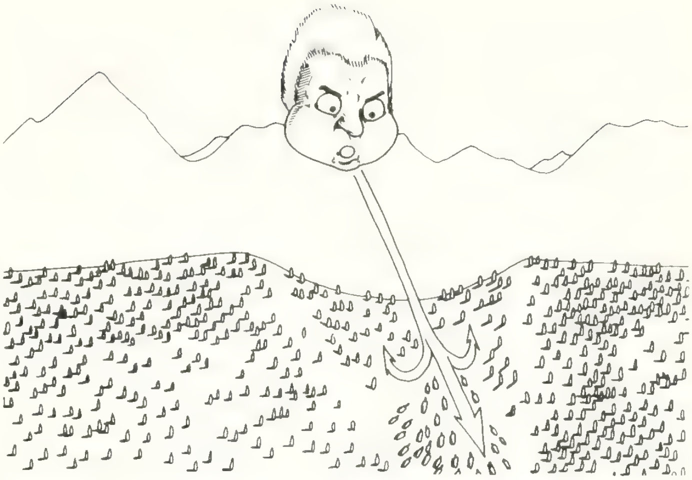


Figure 4.—Very high wind risk; winds funneled through a saddle in a ridgetop.

INSECTS

Keen (1952) listed many insect pests of Engelmann spruce. Of these, the spruce beetle is the most serious (Schmid and Frye 1977). It is restricted largely to mature and overmature spruce (Hopkins 1909; Massey and Wygant 1954; Sudworth 1900a, 1900b). One of the most damaging recorded outbreaks was in Colorado from 1939-51, when beetles killed nearly 4 billion fbm of standing spruce. Damaging attacks have been largely associated with extensive windthrow, where downed trees have provided an ample food supply needed for a rapid buildup of beetle populations (Massey and Wygant 1954, Wygant 1958). Cull material left after logging and road right-of-way clearing also has supported outbreaks, and there are many instances of heavy spruce beetle populations developing in scattered trees windthrown after heavy partial cutting (Wygant and LeJeune 1967). The beetle progeny then emerge to attack living trees, sometimes seriously damaging the residual stand. Occasionally heavy spruce beetle outbreaks have developed in overmature stands with no recent history of cutting or windfall; but losses in uncut stands that have not been subjected to catastrophic windstorms usually have been no greater than normal mortality in old growth (Alexander 1973).

Spruce beetles may emerge from May to July, and trees may be attacked from late May through early August. Beetles feed and breed in the phloem layer. The first evidence of attack is the red boring dust from entrance holes that usually accumulates in bark crevices on the boles and around the bases of infested trees (fig. 5). Small frass-clogged entrance holes may be visible in the bark. Pitch tubes usually are prevalent on the upper bole, where attacks terminate. The needles of killed trees usually turn yellowish green and fall about 1 year after attack; but they may remain green until the second year (Schmid and Beckwith 1971, Schmid and Frye 1977). Frass usually does not accumulate on the ground under windthrown trees or logging residue. Windthrown trees and logging residues do not show pitch tubes. Frass does accumulate in the bark on the bottom surfaces, however.

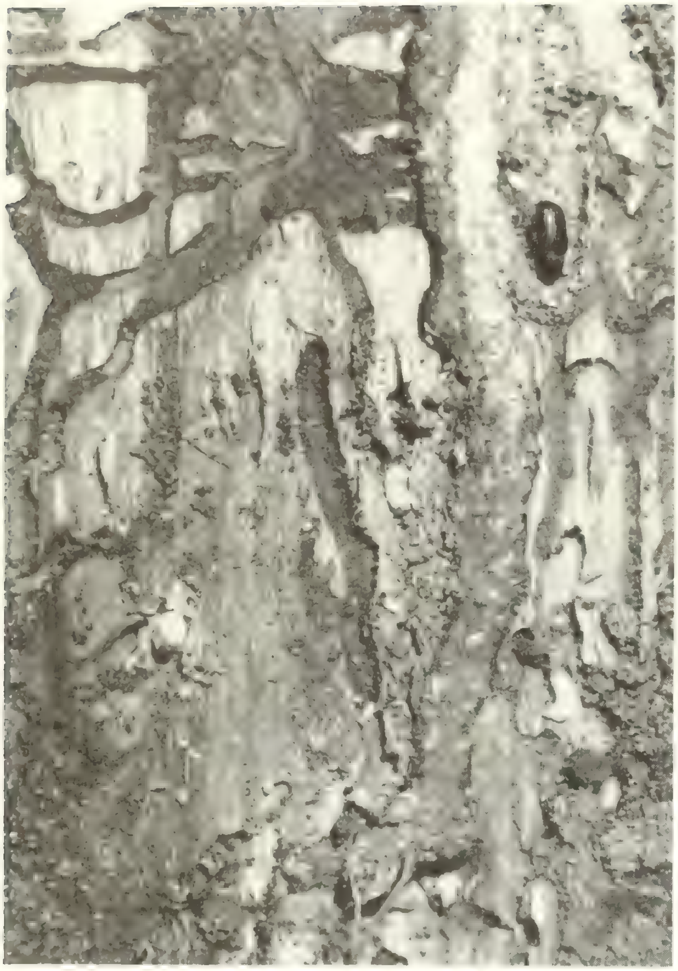


Figure 5.—Engelmann spruce attacked by bark beetles.

Beetles prefer downed material to standing trees; but if downed material is not available, standing trees may be attacked. Overmature trees of large diameter are attacked first; but if an infestation persists, beetles attack and kill smaller diameter trees after the larger trees in the stand are killed. In the central Rocky Mountains, susceptibility of spruce stands, in relation to location, decreases in the following order: (1) trees in creek bottoms, (2) better stands on benches and high ridges, (3) poorer stands on benches and high ridges, (4) mixed stands, and (5) immature stands (Knight et al. 1956, Schmid and Beckwith 1971). Analysis of past infestations suggests the following characteristics are associated with potential outbreaks: (1) single- or two-storied stands, (2) high proportions of spruce in the overstory, (3) basal area of 150 square feet per acre or more in older and larger trees, and (4) an average 10-year periodic diameter growth of 0.4 inch or less (Schmid and Hinds 1974).

Natural factors such as nematodes, insect parasites and predators, and woodpeckers normally maintain beetle populations at low levels, but generally fail to control populations under outbreak conditions. Extremely low temperatures can terminate outbreaks, however, if the insect has not developed cold-hardiness. Temperatures of −15° F under the bark will kill nearly all adults, while −30° F will kill the larvae (Schmid and Beckwith 1971). Certain chemicals are effective in killing spruce beetle but chemical control is expensive and only a temporar measure until potentially susceptible trees can be re moved (Schmid and Frye 1977). In infested stands, o those with potential beetle problems, felling and salvag ing attacked or susceptible trees, and disposing of gree cull material is the most effective silvicultural control i old-growth stands. The buildup of spruce beetle popula tions in logging residue can be minimized by cutting t low stump heights, limbing cull logs and tops then cu ting them into short lengths and scattering them wher they will be exposed to the sun (Schmid 1977). Partia cutting that removes the larger overmature trees an releases the younger trees is another way to reduc potential insect problems in stands with a good stock ing of trees in the smaller diameter classes. "Trap trees intentionally felled prior to beetle flight are highly attrac tive, and often provide an effective way of concentratin and trapping spruce beetles (Nagel et al. 1957). In stati infestations, a ratio of 1 trap tree for every 10 standin infested trees is recommended. This ratio should be 1: for increasing infestations (Schmid and Frye 1977). Afte the beetles enter, the downed logs are usually salvage but may be chemically treated or burned (Schmid an Beckwith 1971). Lethal traps, in which cacodylic acid i used to prevent brood development in trap trees, appea to be a potentially useful refinement to the regular tra tree approach (Buffam et al. 1973). As old-growth is co verted to managed stands of second-growth, control o stand density and maintenance of vigor may be an e fective silvicultural control.

The western spruce budworm (*Choristoneura occiden talis* Freeman) is another potentially destructive insec attacking Engelmann spruce and subalpine fir (Furnis and Carolin 1977, Whiteside and Carolin 1961). Bud worm populations have been contained by combination of several natural control factors—parasites, predators diseases, and adverse climatic conditions.

Subalpine fir is attacked by several groups of insect (Keen 1952), the most important of which is the fi engraver (*Scolytus ventralis* LeConte) (Stevens 1971). Th western balsam bark beetle (*Dryocoetes confusus* Swaine may at times be very destructive locally (Furniss an Carolin 1977).

DISEASES

The most common diseases in spruce-fir stands ar caused by wood-rotting fungi that result in loss of volum (Hinds 1977, Hinds and Hawksworth 1966, Hornibroo 1950) and predispose trees to windthrow and windbrea (Alexander 1964, 1967). Studies of cull indicators an associated decay in Colorado indicated that stand defec caused by wood rotting fungi in mature to overmatur Engelmann spruce ranges from 7% to 26% of the gros volume (Hinds 1977). Trunk rots which cause from 75% to 90% of the decay are associated with *Phellinus pin* (Thore ex Fr.) Karst (=*Fomes pini* (Fr.) Karst) *Haematosterceum sanguinolenta* (Aib. ex Schw. ex Fr. Pouz. (=*Stereum sanguinolentum* (Alb. and Schw. ex Fr. Fr.), *Echinodontium sulcatum* (Bart.) Gross (=*Stereun* lcatum Bart.) and *Amylosterceum chailletii* (Pers. ex Fr.) oid (=*Stereum chailletii* (Pers. ex Fr.) Fr.). Major root id butt fungi are *Phellinus nigrolimitalus* (Rohm.) Bourd. Galz. (=*Fomes nigrolimitatus* (Rom.) Engel.), *Flammula nicola* (Fr.) Kummer (=*Pholiota alnicola* (Fr.) Sanger), *olyporus tomentosus* var. *circinatus* (Fr.) Sartory et aire, *Gloeocystidiellum radiosum* (Fr.) Boid (=*Corticum diosum* (Fr.) Fr.) and *Coniophora puteana* (Schum ex. r.) (Hinds 1977, Hinds and Hawksworth 1966). Most asal decay is associated with old basal wounds and frost acks. Hinds and Hawksworth (1966) provided a means estimating defect in standing spruce based on the average amount of cull associated with specific indicators.

Decay in relation to age, diameter, and site quality has en determined for subalpine fir in Colorado (Hinds 77, Hinds et al. 1960). Stand defect in subalpine fir nges from less than 7% of the volume in trees less than inches d.b.h. to more than 40% in trees larger than inches d.b.h. Trunk rots which account for about 60% 70% of the total defect include *Haematosterceum nguinolenta*, *Phellinus pini*, and *Amylosterceum ailletii*. These decay organisms enter the tree mainly rough wounds or broken branches. Major root and butt ngi are *Gloecystidiellum radiosum*, *Coniophora puteana*, *rmillaria mellea* (Vahl. ex Fr.) Quel., *Coniophorella livacea* (Fr.) Karst (=*Coniophora olivacea* (Fr.) Karst.), *olyporus tomentosus* var. *circinatus*, and *Philiota squar-osa* (Fr.) Kummer).

As old-growth is converted to managed stands, heart ots can be expected to decrease. Early removal of pruce with known indicators of rot, and of fir in the lder age classes will aid in establishing healthy, vigorous orests with a greater growth potential. Rot losses in ture stands can be minimized by shorter cutting otations—140 to 160 years for spruce, and 100 to 120 ears for fir. Careful marking of individual trees to be ut and close supervision of logging operations to reduce echanical injuries minimize points of entry for decay ngi. Proper slash disposal lowers the inoculum poten-al of heart rot fungi in residual stands. These sanita-on methods are important, because direct control of eart rots is not yet possible (Hinds 1977).

Spruce broom rust (*Chrysomyxa arctostaphyli* Diet.) nd fir broom rust (*Melampsorella caryophyllacearum* chroet.) also are common in spruce-fir forests. They ause bole deformation, loss of volume, spiketops, and indbreak, and provide infection courts for decay fungi eterson 1963). Conversion of old-growth to younger igorous stands and sanitation cutting are the only prac-cal means of reducing rust infections.

Dwarf mistletoe (*Arceuthobium microcarpum* (Engelm.) awksworth and Weins) attacks spruce over a limited ange in the Southwest (Hawksworth and Weins 1972). causes top-dieback, defects, provides courts of entry r other diseases and insects, reduces seed production, educes growth and vigor, and may cause severe mor-ality. The largest spruce trees in residual overstories are e most heavily infected, and are the source of infec-on for younger trees. Infection is greater in understory ees with an overstory of older infected trees than in tands without an overstory. While drawf mistletoe infection is heaviest in older and larger trees, all classes are susceptible, even seedlings.

Both subalpine and corkbark firs occasionally are parasitized by dwarf mistletoes whose primary hosts are white fir or Douglas-fir; but these attacks usually are not damaging (Mathiasen and Hawksworth 1983). Separation of the old and new stands by clearcutting and felling unmerchantable residual trees appears to be the best way to control dwarf mistletoe. In areas of high tree values, such as recreational, administrative, and home sites, infected branches can be pruned from lightly infected trees; but heavily infected trees must be cut. Partial cutting and thinning generally create ideal conditions for maximum infection and should be avoided where possible, unless the infection is light.

FIRE

Historically, wildfires have burned over large areas where spruce-fir forests grow today. Thin bark, the persistence of dead lower limbs and shallow root systems make spruce and fir susceptible to destruction or severe injury by fire. Moreover, fire damage to the roots and boles predisposes spruce and fir to windthrow and windbreak. However, because of the moist environments where spruce and fir grow, the risk of fire is less than in warmer climates, and relatively few acres have burned in the last 300 to 400 years (Alexander and Shepperd 1984). When severe wildfires do occur, spruce-fir forests may be converted to grass and other low vegetation cover that will persist for considerable time.

ANIMALS

Animals rarely damage established spruce and fir trees. Mule deer (*Odocoileus hemionus* Rafinesque) and elk (*Cervus elaphus* L.), when yarded up in the winter, may browse fir and spruce to some extent. While fir is more palatable than spruce, both species are likely to be taken only as a last resort. Moreover, the spruce-fir type occurs in areas of heavy snowpack not suitable for winter range. Bears (*Ursus* spp.) and porcupines (*Erethizon dorsatum* Brandt) occur in spruce-fir forests but seldom damage these trees.

CUTTING HISTORY

Limited areas of the original spruce-fir forests were logged in the late 1800s to provide fuel, lumber, and timbers for early mining camps. Although cutting on the national forests dates back more than 70 years, only relatively small quantities of timber were harvested until the 1950s. Cutting has accelerated rapidly since then.

Most cuttings in spruce-fir forests before 1950 in the central and southern Rocky Mountains could be collectively called "partial cuttings." They ranged from removal of a few individual trees to removal of all the larger, more valuable trees in the stand. Seedbed preparation usually was limited to the disturbance created by logging, and slash was untreated or lopped. Most skidding was done with horses.

In general, heavy partial cutting—usually considered necessary to make logging profitable—was not a successful means of arresting stand deterioration or increasing net increment on residual trees, even though most of these cuttings successfully regenerated a new stand. For example, residual stands of spruce-fir in Colorado suffered heavy mortality when 60% of the original volume was removed in the first cut of a two-cut shelterwood (Alexander 1956, 1963) (fig. 6). Net increment was only about one-third of that in uncut stands. Similar results followed heavy partial cutting elsewhere in the central Rocky Mountains (USDA Forest Service 1933), and in the northern Rockies (Roe and DeJarnette 1965). Even when mortality was not a problem, heavy partial cutting left the older, decadent stands in a shabby condition, with little appearance of permanent forest cover.

Windfall, the principal cause of mortality, increased as the intensity of cutting increased. Low stumpage values and the generally scattered pattern of windfall usually prevented salvage of blowdown after partial cutting. Not only was the volume of windthrown trees lost, but the combination of downed spruce and overstory shade provided breeding grounds for spruce beetles.

Partial cutting was successful—in that the residual stand did not suffer heavy mortality and stands were regenerated—in some spruce-fir stands where large reserve volumes were left in protected locations. In one study in northern Idaho, windfall losses were light after a partial cutting that left a residual stand of 6,000 board feet (fbm) per acre in a sheltered location on deep, well drained soil (Roe and DeJarnette 1965). On the Grand Mesa National Forest in Colorado, where spruce trees are relatively short and there are no serious wind problems associated with topography, few trees blew down when about 40% of the original volume was removed from two-storied stands. In single-storied stands, however, only about 30% of the original volume could be safely removed. In contrast, heavier partial cutting that removed 50% or more of the original volume per acre from spruce-fir forests in the dry "rain shadow" of the Continental Divide on the Rio Grande National Forest did not result in blowdown to the residual stand. However, these two-storied stands were growing on sites where productivity was very low. Individual trees were short, widely spaced, and, therefore, relatively windfirm before cutting.

There are also numerous examples of early cuttings—between 1910 and 1930—on many national forests in Colorado, where very light partial cutting—removal of 10% to 15% of the stand—did not result in substantial windthrow of residual trees. Although an overstory tends to favor fir reproduction over spruce, regeneration success of spruce has been acceptable under a wide variety of partial cutting treatments (Alexander 1963, Roe and DeJarnette 1965).

In the early 1950s harvesting shifted to clearcutting. The first clearcuttings were in narrow strips (200 to 400 feet wide) (fig. 7) or small patches or groups that sim-

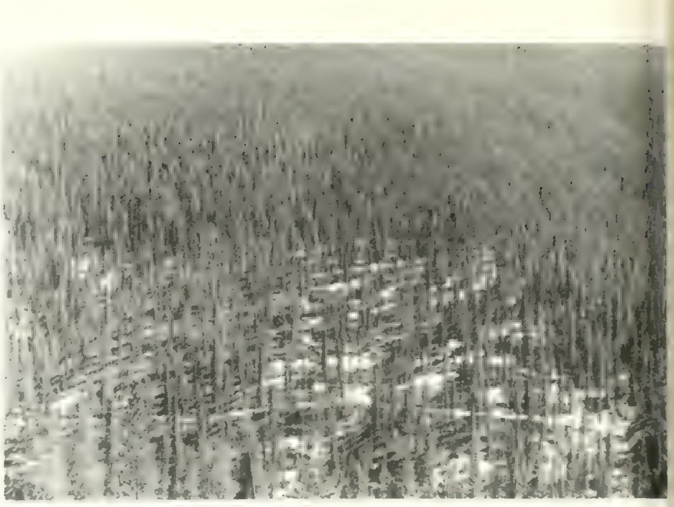


Figure 6.—Two-cut shelterwood that initially removed 60% of the volume in a spruce-fir stand, Fraser Experimental Forest.

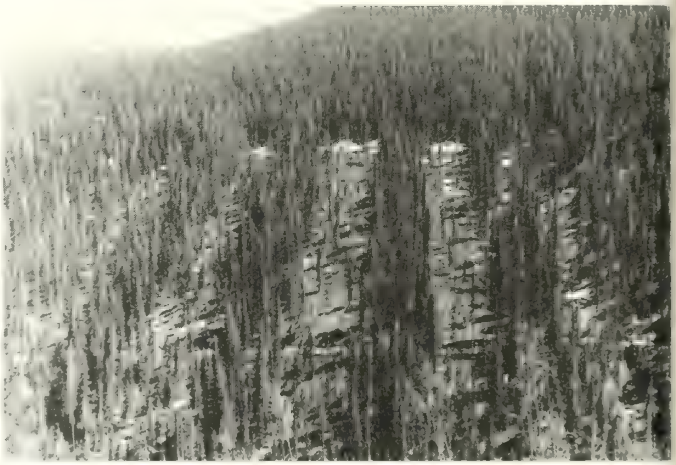


Figure 7.—Clearcutting that removed 50% of the volume in alternate strips in a spruce-fir stand, Fraser Experimental Forest.

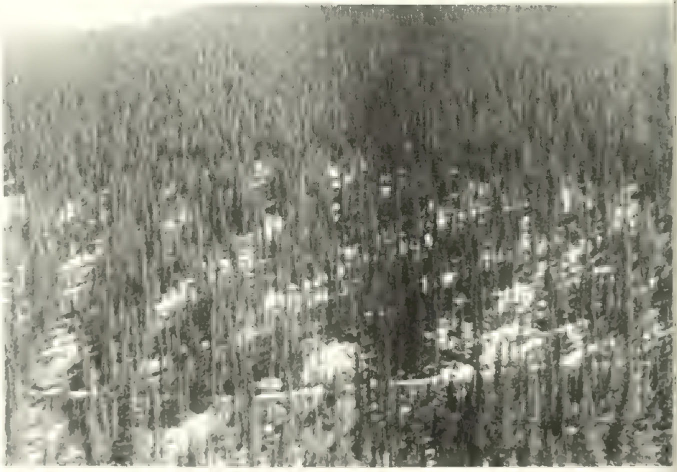


Figure 8.—Group selection that removed 50% of the volume in a spruce-fir stand in openings on one-third of the area about one tree height in diameter, Fraser Experimental Forest.

ulated group selection cutting (fig. 8) with little seedbed preparation or slash disposal. Advanced regeneration was not completely destroyed. In general, windfall losses were less than after heavy partial cutting, and the cutovers usually were adequately restocked with a combination of surviving advanced and new reproduction (Alexander 1956, 1957, 1963, 1966, 1968). By the late 1950s, the common practice was to clearcut in large blocks, patches, or wide strips. These larger openings were justified as being more effective in controlling spruce beetles and in reducing logging costs. Slash and cull material were either broadcast burned, bulldozer piled, or windrowed and burned. Hazards from fire and insects were reduced; but removal of all slash, cull material, and residual trees left the seedbeds devoid of shade, thereby creating a difficult microenvironment for the establishment of either natural or artificial regeneration (Roe et al. 1970, Ronco 1970). Furthermore, the destruction of advanced reproduction usually was an unnecessary loss of valuable growing stock.

In the 1970s, after nearly 20 years of harvesting spruce-fir almost exclusively by clearcutting, there was a shift in cutting practices to either some form of partial cutting, usually shelterwood, or a combination of partial cutting and small cleared openings without complete cleanup of slash and other logging debris (Alexander 1973). This shift was necessary because clearcutting large areas often (1) resulted in adverse visual and environmental impacts, (2) was incompatible with the objectives of other forest uses, and (3) led to regeneration failures. Today, spruce-fir forests are harvested by a variety of cutting methods (Alexander 1977, Alexander and Engelby 1983).

REGENERATION SILVICULTURAL SYSTEMS

Both even- and uneven-aged silvicultural systems can be used to regenerate spruce and fir. The forests can be harvested by clearcutting, shelterwood, and selection cutting, and by modifications of these methods. The seed-tree cutting method is not a suitable method of regenerating spruce-fir stands because of susceptibility to windfall (Alexander 1977, Alexander and Engelby 1983). The objective of each regeneration system is to harvest the timber crop and obtain adequate reproduction. The choice of cutting method depends on management objectives and environmental considerations; but stand conditions, associated vegetation, and windfall and spruce beetle susceptibility that vary from place to place on any area, impose limitations on how individual stands can be handled. Cutting to bring old-growth under management is likely to be a compromise, therefore, between what is desirable and what is possible. Management on many areas may involve a combination of several partial cutting treatments, clearcutting, and sanitation salvage cutting (Alexander 1973, 1974, 1977).

EVEN-AGED CUTTING METHODS

Even-aged cutting methods—clearcutting and shelterwood—have been used almost exclusively in spruce-fir stands since the mid-1950s because of several factors.

Spruce and fir, although fairly shade-tolerant, frequently do not have the age-class structure normally associated with shade-tolerant species. They often tend to be even-aged or even-sized rather than all-aged (LeBarron and Jemison 1953).

Many spruce-fir stands are overmature. One way to bring these stands under management is to harvest the old-growth, either in one operation or over a short period of time, and replace it with a new stand.

Heavy partial cutting or clearcutting generally reduces the cost of logging, because fixed costs are spread over a greater volume of timber removed.

Frequent entry with light cuts favor the more shade-tolerant and less valuable firs. These species are especially vulnerable to logging damage and subsequent decay.

Management with Advanced Regeneration

Simulated Shelterwood Cutting

This cutting method removes the overstory from a manageable stand of advanced reproduction in one or more operations (fig. 9). It simulates the final harvest of a standard shelterwood. This option can be used in stands where trees are either uniformly spaced or where they are clumpy, groupy, or patchy.

Although many spruce-fir forests have an understory of advanced growth, and these trees will respond to release after cutting, wide variations in age, composition, quality, and quantity of advanced reproduction require careful, precutting evaluation of the potential for future management. This evaluation should include site quality and habitat type. One course of action is followed if the advanced reproduction is to be managed, another if a manageable stand is not present, cannot be saved, is not expected to grow well, or the manager chooses to destroy it and start over (Roe et al. 1970).

Prelogging evaluation.—The initial examination must answer the following questions: (1) How much of the area is stocked with acceptable seedlings and saplings, and will that stocking insure a satisfactory replacement

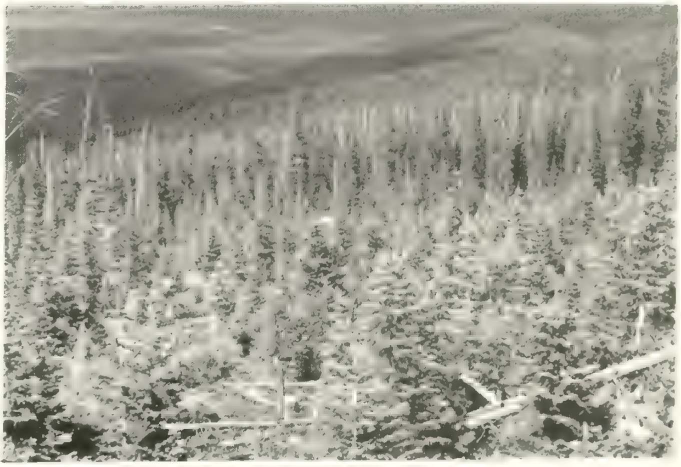


Figure 9.—Simulated shelterwood in an old-growth spruce-fir stand, Fraser Experimental Forest.

stand? (2) Can it be logged economically by methods that will save advanced reproduction? Is the timber volume too heavy to save advanced reproduction if it is removed in one cut? (3) How much of the area will require subsequent natural or artificial regeneration, either because advanced reproduction is not present or will be damaged or destroyed in logging?

Because any kind of cutting is likely to destroy or damage at least 50% of the advanced growth, a manageable stand of advanced reproduction before cutting should contain at least 600 acceptable seedlings and saplings per acre, at least 50% of which should be spruce. There are few data available on the growth response of advanced reproduction after release in the central and southern Rocky Mountains; but in the Intermountain Region, McCaughey and Schmidt (1982) found that both advanced spruce and fir regeneration made good height growth after clearcutting and partial cutting. The following criteria, therefore, are based largely on experience and observations. To be acceptable, reproduction must be of good form, able to make vigorous growth when released, and be free of defect or mechanical injury that cannot be outgrown. Trees larger than 4 inches d.b.h. may be acceptable; but they should not be included in the prelogging regeneration survey, because they are more likely to be damaged or destroyed in logging, or windthrown after logging. Stands or portions of stands not meeting these criteria have to be restocked with subsequent natural or artificial regeneration (Roe et al. 1970).

Cutting and slash disposal treatment.—Mature and overmature trees should be cut to release advanced reproduction and harvest merchantable volume. Seed sources need not be reserved from cutting unless required for fill-in stocking. The size, shape, and arrangement of units cut is not critical for regeneration; but to be compatible with other key uses, they should be no wider than about five to eight times tree height, should be irregular in shape, and blend into the landscape. Not more than one-third of any drainage or working circle should be cut over at any one time.

Protection of advanced reproduction begins with a well-designed logging plan (Roe et al. 1970). Logging equipment and activity must be suited to the terrain and rigidly controlled to minimize damage to advanced reproduction and disturbance to soil. Skid roads should be located at least 200 feet apart and marked on the ground before cutting. Skidding equipment should be moved only on skid roads. Where possible, trees should be felled into openings at a herringbone angle to the skid road to reduce disturbance when logs are moved onto the skid road (Alexander 1957, Alexander 1974, Roe et al. 1970). It may be necessary to deviate from a herringbone felling angle in order to drop the trees into openings. In this case, the logs will have to be bucked into short lengths to reduce skidding damage. Furthermore, the felling and skidding operations must be closely coordinated, because it may be necessary to fell and skid one tree before another is felled. Dead sound material and snags that are felled should be skidded out of the area to minimize the amount of slash and unmerchantable material. In stands with heavy volumes per acre, it ma be necessary to remove the overstory in more than on cut (Alexander 1974).

Slash treatment then should be confined to areas o heavy concentrations as required for protection from fir and insects or preservation of esthetic values (Roe et al 1970). Slash also must be treated carefully to avoi damage to advanced reproduction. If trees are felled in to openings as much as possible, a minimum of turnin and travel with brush dozers will be needed to concentrate the slash for burning. Slash piles should confin burning to the smallest area possible.

Postlogging reevaluation.—Even with careful loggin and slash treatment, some advanced reproduction wil be damaged or destroyed. The area must be surveyed to (1) Determine the extent of damage to the reproduction At least 300 acceptable seedlings and saplings per acre of which at least 50% should be spruce, must have survived to consider the area adequately stocked. This i in addition to any trees larger than 4 inches d.b.h. tha survived. Areas that do not meet these standards nee fill-in or supplemental stocking. (2) Plan stand improvement—cleaning, weeding, and thinning—to release cro trees. Cutover areas should not be considered in an adequate growing condition until the crop trees are free t grow and the necessary fill-in planting or natura regeneration is complete (Roe et al. 1970). It is especially important to fell larger reproduction that has bee broken off or sustained basal wounds. These trees ca occupy significant areas and eventually become cull because of decay.

Management for Regeneration After Cutting

Clearcutting

This method harvests the timber crop in one step t establish a new stand. Because a large proportion of th spruce-fir type is in overmature sawtimber stands tha have little potential for future management because o their advanced age, relatively slow growth, and susceptibility to wind and insects, forest managers concerne with timber production have usually decided to conver old-growth to managed stands by clearcutting in strips patches, and blocks (fig. 10). Therefore, harvesting an regeneration practices developed in the central Rock Mountains have been directed toward this objective Much of the criticism of past clearcutting operations i spruce-fir can be attributed in part to poor cutting practices, particularly where large openings were cut geometric patterns that did not complement the landscape were used, unsightly logging debris was left on th ground, and areas were not regenerated. However, from a silvicultural point of view, clearcutting, properly done is still an acceptable harvesting method in spruce-fi forests (Alexander 1974, 1977, Alexander and Engelb 1983).

Cutting unit layout, logging plans, slash disposal, an seedbed treatment should be designed to (1) facilitat seed dispersal, (2) promote seedling survival and establishment, and (3) create favorable growing conditions

If natural regeneration fails, plans must be made to use artificial regeneration (Roe et al. 1970). Clearcutting can be readily adapted to multiple use land management by judicious selection of size, shape, and arrangement of openings in combination with other high-forest cutting practices (Alexander 1974, 1977).

Size of cutting unit.—Requirements for seed dispersal and site preparation will influence the size of opening that will restock naturally (Roe et al. 1970). The cutting unit must be designed so that seed from the surrounding timber margin reaches all parts of the opening, unless supplementary artificial regeneration is planned. Effective seeding distance and aspect determine the size of opening.

The tabulations that follow are guides developed for the central Rocky Mountains. They are based on 20 years of seed production and dispersal data from six areas in Colorado (Alexander 1969, Alexander and Edminster 1983, Alexander et al. 1982, Noble and Ronco 1978), and 15 years of spruce survival data from the Fraser Experimental Forest in Colorado in an *Abies lasiocarpa/Vaccinium scoparium* habitat type (Alexander 1983, 1984). Effective seeding distance, as used here, is defined as the distance to which sufficient sound seed is dispersed to provide 800 5-year-old seedlings—a desirable stocking goal for Engelmann spruce (Alexander and Edminster 1980)—on (1) mineral soil seedbeds where competition from competing vegetation has been eliminated, and 50% overhead shade and protection from rodents has been provided; (2) on unshaded mineral soil seedbeds where competing vegetation has been removed and protection from rodents has been provided; (3) natural seedbeds with 50% overhead shade and protection from rodents provided; and (4) natural unshaded seedbeds with only protection from rodents provided.

The number of 5-year-old seedlings expected to become established on two aspects in relation to the number of sound seeds is as follows.

Seedbed and aspect	Seedlings per 1,000 sound seeds
Shaded mineral soil	
North	31
South	3
Unshaded mineral soil	
North	13
South	0
Shaded, natural	
North	14
South	3
Unshaded, natural	
North	2
South	0

The estimated maximum distance that can be seeded from all sides and maximum size of opening that can be restocked in 5 years on two aspects, based on an accumulative 5-year seed production of 500,000 sound seeds per acre, is as follows (Alexander 1983, 1984; Alexander and Edminster 1983, Alexander et al. 1982).

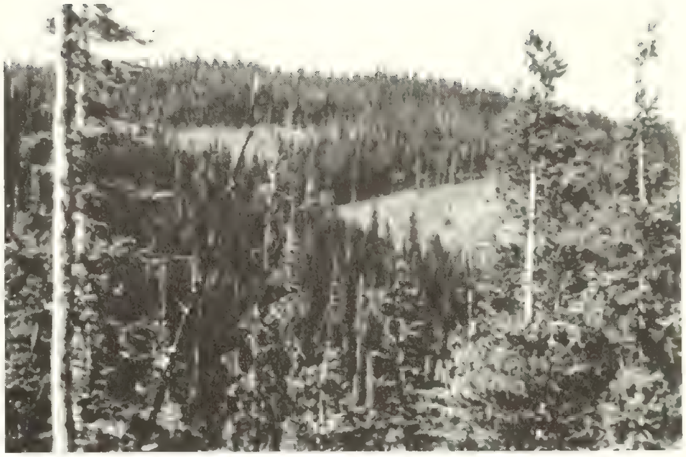


Figure 10.—Clearcutting in small patches in an old-growth spruce-fir stand, Fraser Experimental Forest.

Seedbed and aspect	Maximum distance that can be seeded (feet)	Maximum size opening (tree heights)
Shaded, mineral soil		
North	400–450	5–6
South	50–100	1–1.5
Unshaded, mineral soil		
North	300–350	4–5
South	0	0
Shaded, natural		
North	300–350	4–5
South	50–100	1–1.5
Unshaded, natural		
North	0	0
South	0	0

Based on these seeding distances, four conclusions can be drawn.

1. Clearcutting with natural regeneration is most likely to succeed on north and east aspects, if the right combination of mineral soil and shade has been created. Even then, more than one good seed year will likely be required to obtain adequate restocking.
2. Clearcutting on south and west aspects is not likely to result in an acceptable stand of new reproduction in a reasonable period of time, even with favorable seedbed and environmental conditions, without fill-in planting to bring reproduction to the minimum acceptable standard.
3. Where larger openings than shown are cut on north and east aspects, it will be necessary to plant the area beyond the effective seeding distance.
4. Where the seed source is of poor quality, plan to plant the cutovers.

Similar guides developed for Intermountain Region conditions by Roe et al. (1970) suggest that openings larger than those indicated here (up to 660 feet, or about 8 times tree height) can be restocked on north aspects if the seed source contains 200 or more square feet of basal area in spruce trees 10 inches d.b.h. and larger; but openings of only 200 to 400 feet wide are likely to restock on south aspects. Effective seeding distance with a light seed source (70 square feet of basal area or less) will vary from 0 to 200 feet on north aspects and be 0 on other aspects.

Windfall.—The following guidelines for minimizing windfall around the perimeter of clearcut openings were developed in Colorado (Alexander 1964, 1967, 1974).

1. Protection from wind for the vulnerable leeward boundaries is most important.
2. Do not locate cutting boundaries where they will be exposed to accelerated winds funneling through saddles in ridges to the south and west of the cutover area, especially if the ridges are at high elevations (fig. 4).
3. Avoid locating cutting boundaries on ridges or directly below saddles in ridges (fig. 11), especially ridgetops of secondary drainages to the lee and at right angles to the main drainage when the latter is a narrowing valley with steep slopes. One cutting unit should straddle each ridgetop and extend downslope in both directions for a distance of at least 200 feet. That unit may be cut or uncut. Such an arrangement will avoid leaving a cutting boundary on the top of a ridge (fig. 12).
4. Where topography, soils, and stand conditions permit, lay out each unit so that the maximum amount of cutting boundary is parallel to the contour or along a road (fig. 13).
5. Do not lay out cutting units with dangerous wind-catching indentations (fig. 14) or long, straight lines and square corners in the leeward boundary or in boundaries that are parallel to storm winds. V- or U-shaped identations in the boundary can funnel wind into the reserve stand. Long, straight cutting boundary lines and square corners also deflect the wind and cause increased velocities where the deflected currents converge like a windstream flowing over a crest. Irregular cutting boundaries without sharp identations or square corners lessen the opportunity for deflection and funneling of air currents.
6. Do not locate boundaries on poorly drained or shallow soils. Trees grown under these conditions are shallow rooted and susceptible to windthrow.
7. Locate cutting boundaries in stands of sound trees. Trees with decayed roots and boles or root systems that were cut or torn during road building or log skidding operations are poor windfall risks.
8. Locate cutting boundaries in immature stands when possible. Stands of young trees usually are less easily uprooted by strong winds.
9. Locate cutting boundaries in poorly stocked stands. Open-grown trees are more windfirm than trees grown in dense stands.
10. Avoid locating cutting boundaries in areas where there is evidence of old prelogging blowdowns.
11. Reduce blowdown in areas with exceptionally hazardous windfall potential by locating the vulnerable leeward boundaries where hazards are below average, or by eliminating those boundaries by progressive cutting into the wind.

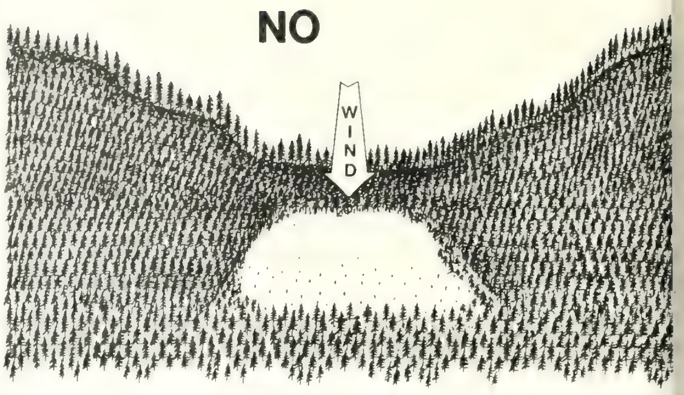


Figure 11.—Clearcut opening directly below a saddle where wind vortexing can occur and increase blowdown risk.

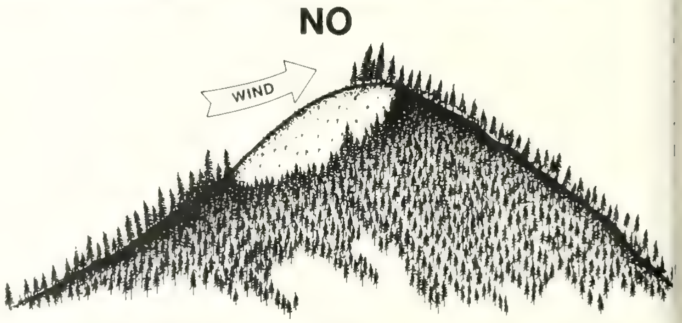


Figure 12.—Clearcut unit boundary on a ridgetop where risk of blowdown is increased.

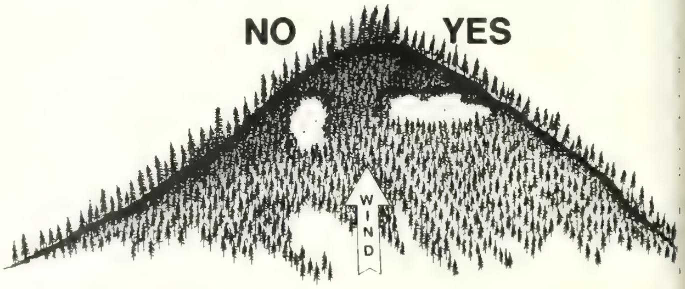


Figure 13.—Clearcut unit boundaries laid out across the slope that expose the short dimensions of the unit to the wind helps reduce blowdown.

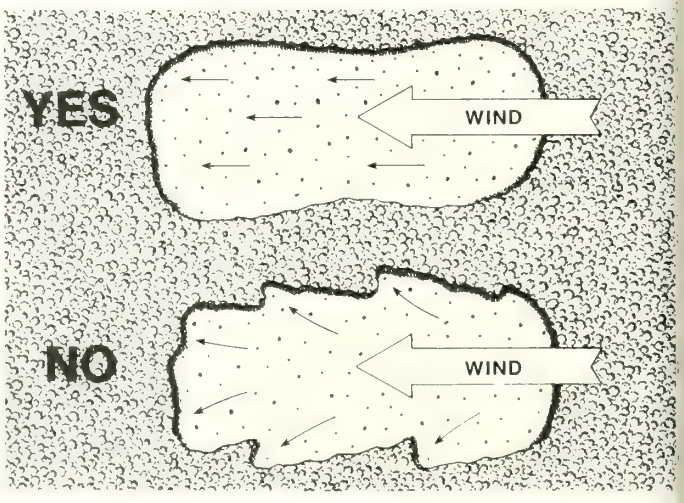


Figure 14.—Irregular cutting boundaries without sharp indentations or square corners help reduce blowdown.

Slash treatment and site preparation.—Slash 8 inches in diameter or larger provides a habitat for spruce beetles; it provides beneficial shade for germination and seedling establishment; in heavy concentrations, it obstructs natural seedling establishment; and it creates an adverse visual impact (Alexander 1974).

Burning slash in large concentrations, such as windrows or piles, often creates enough heat in the soil to inhibit the development of any kind of plant growth for an unknown period of time. Therefore, windrows or piles should be small or narrow, and cover a minimum proportion of the area (Roe et al. 1970).

Mineral soil can be exposed by mechanically scarifying the ground surface, sometimes in connection with slash disposal or by broadcast burning. To be effective, broadcast burning should consume most but not necessarily all of the duff or organic material on the ground, and it should burn hot enough to destroy some or all of the competing vegetation. However, it should not burn so hot that a deep layer of loose ash accumulates, the mineral soil changes color, or the rocks fracture. It must leave cull logs, tops, and other large slash to provide shade and protection for soil and seedlings. Timing of the burn is exceedingly important. The spruce type is generally so cool and moist that times for effective broadcast burning are limited. Burn when the duff is dry enough to be consumed. If only the surface is dry, a blackened organic layer that inhibits seedling establishment will remain (Roe et al. 1970).

Often, logging disturbance alone will be sufficient site preparation, and soil surface conditions should be inspected immediately after logging to determine whether additional site preparation is needed. If so, careful mechanical scarification will prepare a satisfactory seedbed if it exposes mineral soil and destroys some of the competing vegetation, but leaves shade protection. At least 40% of the area should be left as exposed mineral soil. It may be necessary, however, to rearrange some of the residual slash to provide adequate shade. Tractors equipped with brush blades should be used. A complete cleanup job is neither necessary nor desirable for two reasons. First, residual tops and slash shade the seedbed. Second, residual organic material reduces soil erosion. Cut green spruce material larger than 8 inches in diameter should be removed or treated to prevent the buildup of spruce beetle populations; but fir material may be left. On highly erodible soils, the duff layer should be removed along the contour, preferably in strips the width of the dozer blade, with untouched strips intervening. Some of the larger debris then may be pushed back on the scarified strips for protection from erosion, and the dozer may be walked over it at right angles to the strips to break it down (Alexander 1974, Roe et al. 1970).

Shelterwood Cutting

This regeneration cutting method harvests a timber stand in a series of cuts. In a standard shelterwood, the new stand regenerates under the shade of a partial overstory canopy. The final harvest removes the shelterwood and permits a new stand to develop in the opening. In a group shelterwood (a modification of the shelterwood method), the new stand regenerates in small openings that leave standing trees around the margins as a seed source. Openings are too small (2 acres or less) to be classified as a clearcut (U.S. Department of Agriculture 1983). This kind of cutting has been incorrectly called a modified group selection, but differs from a selection cut in the way the growing stock is regulated.

These cutting methods may be the only even-aged options open to the manager where (1) multiple use considerations preclude clearcutting, (2) combinations of small cleared openings and high forests are required to meet the needs of various uses, or (3) areas are difficult to regenerate after clearcutting. However, shelterwood cutting requires careful marking of individual trees or groups of trees to be removed, and close supervision of logging. The following recommendations for shelterwood cutting practices are keyed to broad stand descriptions based largely on experience, windfall risk situations, and insect problems (Alexander 1973, 1974). Practices needed to obtain natural reproduction are also discussed.

Single-storied stands.—Stands may appear to be even-aged (fig. 15), but usually contain more than one age class. Canopy may not appear to be of a uniform height because of changes in topography, stand density, or stocking. Codominant trees form the general level of the overstory canopy. Dominants may be 5 to 20 feet above the general canopy level. Taller intermediates extend into the general canopy; shorter intermediates are below the general canopy level but do not form a second story. Range in diameters and crown length of dominants and codominants is small.

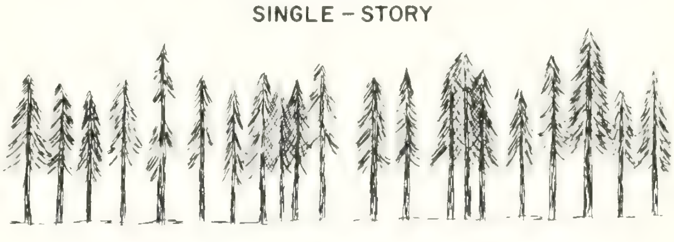


Figure 15.—A single-storied spruce-fir stand.

There are few coarse-limbed trees in the stand; if two-aged or more, younger trees usually have finer branches and smaller diameters than the older trees. Trees are more often uniformly spaced than clumpy. There usually is not a manageable stand of advanced reproduction. Lodgepole pine is absent or sparse.

These stands usually are the least windfirm because trees have developed together over a long period of time and mutually protect each other from the wind.

If windfall risk is low, and trees are uniformly spaced, the first cut should remove about 30% of the basal area of the stand on an individual tree basis (fig. 16). It resembles the preparatory cut of a three-step shelterwood. Because all overstory trees are about equally susceptible to windthrow, the general level of the canopy should be maintained by removing some trees from each crown class. Those trees with known indicators of defect should be removed first; but avoid creating openings in

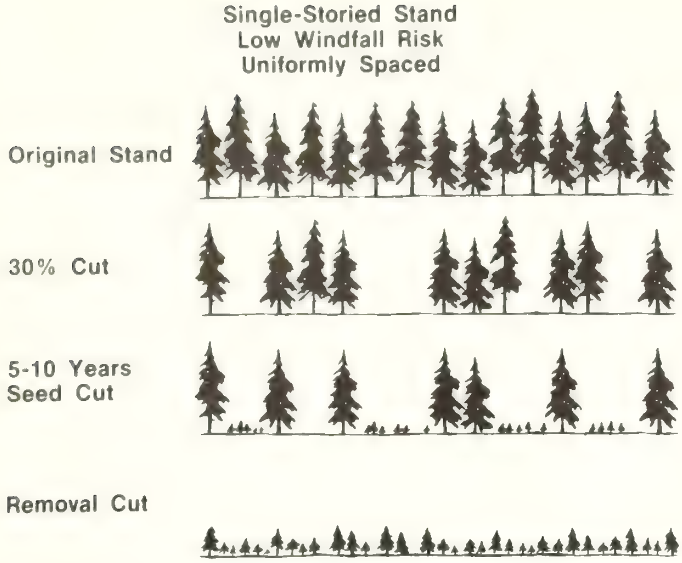


Figure 16.—Sequence of entries with a 3-cut shelterwood in a uniformly-spaced, single-storied spruce-fir stand in a low windfall risk situation.

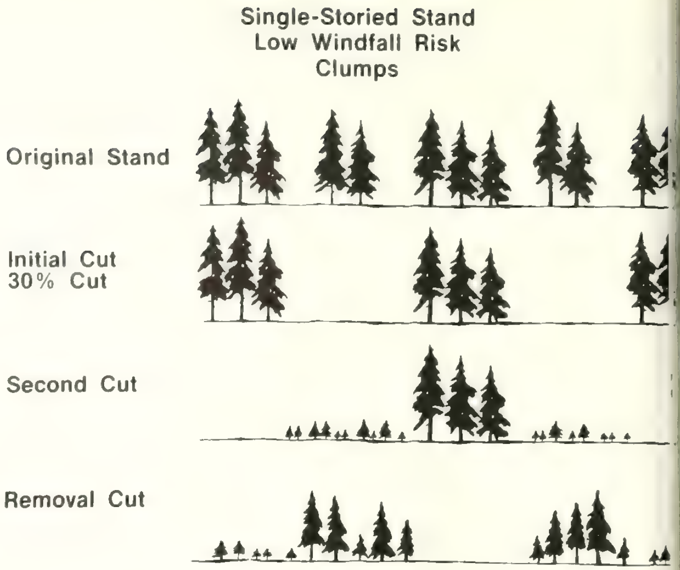


Figure 17.—Sequence of entries with group shelterwood in a clumpy-spaced, single-storied spruce-fir stand in a low wind risk situation.

the canopy with a diameter larger than one tree height by distributing the cut over the entire area. Do not remove dominant trees in the interior of the stand that are protecting other trees to their leeward if these latter trees are to be reserved for the next cut. In these, and all other stands described with natural openings of one to several acres, leave the trees around the perimeter for a distance of about one tree height until the final entry. These trees have been exposed to the wind and are usually windfirm, and protect the trees in the interior of the stand.

The second entry into the stand should be delayed for 5 to 10 years after the first cut in order to determine if the residual stand is windfirm. This cut should also remove about 30% of the original basal area on an individual tree basis. It simulates the seed cut of a three-step shelterwood. The largest and most vigorous dominants and codominants should be reserved as a seed source; but avoid cutting openings in the canopy larger than one tree height in diameter by distributing the cut over the entire area, even if it means leaving trees with poor seed production potential.

The last entry into these uniformly-spaced stands is the final harvest, which should remove all of the remaining original overstory. It should not be made until a manageable stand of reproduction has become established; but the cut should not be delayed beyond this point if timber production is one of the primary concerns, because the overwood hampers the later growth of seedlings.

The manager also has the option of removing less than 30% of the basal area at any entry and making more entries; but they cannot be made more often than every 5 to 10 years. This will spread the cut over time and maintain a continuous forest cover longer.

If windfall risk is low, but trees are clumpy or groupy, the first cut should be a group shelterwood that removes about 30% of the basal area. Harvesting timber in groups will take advantage of the natural arrangement of trees. Openings should be kept small—not more than one or two tree heights in diameter—and not more than one-third of the area should be cut over (fig. 17). All trees in a clump should be either cut or left, because they mutually support each other, and removing only part of a clump is likely to result in windthrow of the remaining trees.

The second entry into the stand should not be made until the first group of openings has regenerated. This cut also removes about 30% of the original basal area without cutting over more than an additional one-third of the area. Openings should be no closer than about one to two tree heights to the openings created by the initial cut.

The final entry into these clumpy or groupy stands should remove the remaining groups of merchantable trees. Timing of this cut depends upon how the manager decides to regenerate the new openings. If it is by natural regeneration, the final harvest must be delayed until the regeneration in the openings cut earlier is large enough to provide a seed source.

In these stands, the manager may again choose to remove less than 30% of the basal area and cut over less than one-third of the area at any one time. This will require more entries; but no new cuttings should be made until the openings cut the previous entry have regenerated. The last groups cannot be cut until there is either a seed source or the manager elects to plant these openings.

If windfall risk is above average (moderate), and trees are uniformly spaced, there are two alternatives. In Alternative 1 (fig. 18), the first cut should be a very light preparatory cutting that removes about 10% of the basal area on an individual tree basis, to open up the stand while minimizing windfall risk to the residual trees. This cutting resembles a sanitation cut in that the poorest risk trees—those of low vigor and with known indicators of

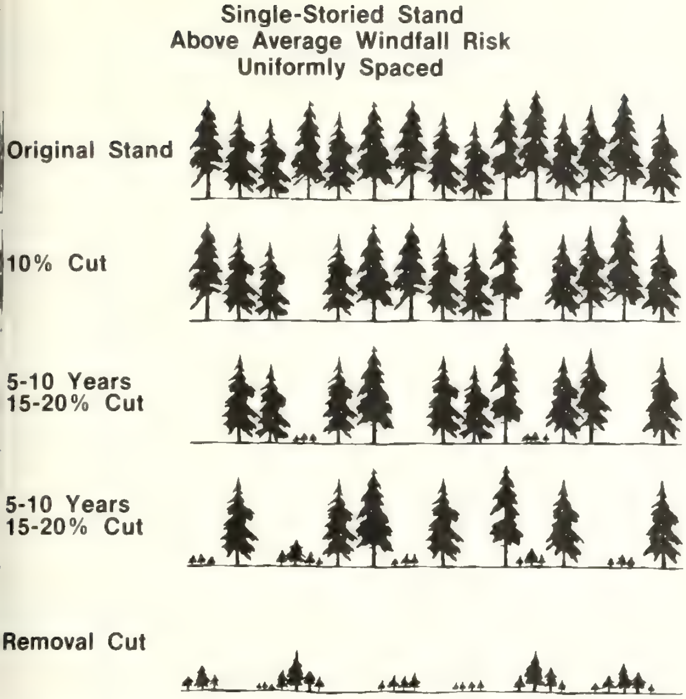


Figure 18.—Sequence of entries for Alternative 1 with a shelterwood in a uniformly-spaced, single-storied spruce-fir stand in an above-average wind risk situation.

defect—and predominants should be removed; but it is important to maintain the general canopy level. Provision should be made to salvage any postharvest windfalls after spruce beetle flight at the end of July.

The second entry can be made about 10 years after the first cut. This entry should remove about 15% to 20% of the original basal area on an individual tree basis. Any windfall salvaged after the first cut should be included in the computation of the basal area to be removed. This preparatory cut is intended to continue opening up the stand gradually preparing for the seed cut. Most of the trees marked for removal should be intermediates and small codominants; but the general canopy level should be maintained.

It will require another 5 to 10 years to determine if the stand is windfirm enough to make another entry. This entry is seed cut, and should remove about 15% to 20% of the basal area, including any windfalls salvaged since the last cutting. The largest and most vigorous dominants and codominants should be reserved as a seed source, but it is also important to distribute the cut over the entire area.

The last entry is the final harvest to remove the remaining overstory. It cannot be made until a manageable stand of reproduction has established. About 50% of the basal area will be removed in this cut. If this volume is more than 10,000 fbm per acre, it is probably too heavy to be removed in one harvest without undue damage to the reproduction. The manager must plan on a two-step final harvest. The second step can begin as soon as the skidding is finished in the first step, provided that a manageable stand of reproduction still exists.

In Alternative 2 (fig. 19) in evenly-spaced stands with moderate windfall risk, the first entry is the same as under Alternative 1. The second and third entries are made at 5- to 10- year intervals. Each entry removes about 10% of the basal area. The objectives are still to open up the stand, minimize windfall risk, and remove the poorest risk trees.

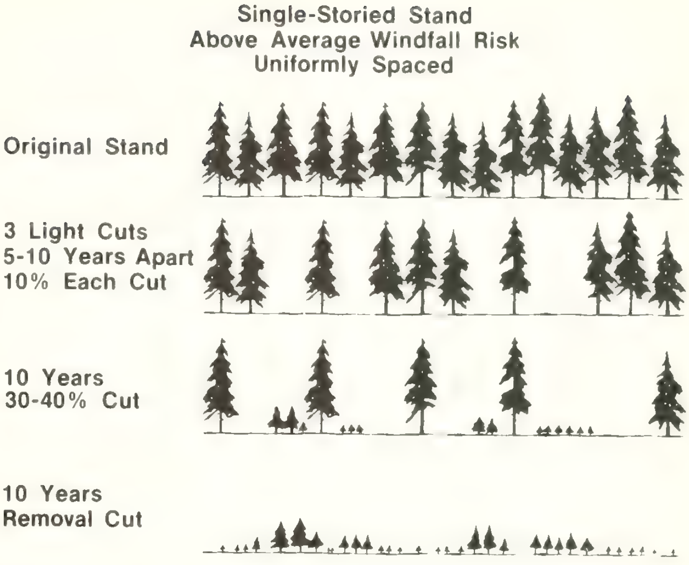


Figure 19.—Sequence of entries for Alternative 2 with a shelterwood in a uniformly-spaced, single-storied spruce-fir stand in an above-average wind risk situation.

The fourth entry is the seed cut that will be made about 10 years after the third entry, and remove 30% to 40% of the basal area including any windfall salvaged since the last cutting. The largest and most vigorous dominants and codominants should be left as a seed source; but distribute the cut over the entire area.

The last entry is the final harvest to remove the remaining 30% to 40% of the basal area. It cannot be made until there is a manageable stand of reproduction.

Alternative 2 is somewhat risky, because it increases the chances of blowdown; but it encourages a better stand of reproduction, because the stand is opened up more at the seed cut.

If windfall risk is above average and trees are clumpy, the first cut should be light, removing about 10% to 20% of the basal area in a group shelterwood (fig. 20). Openings should be no larger than one tree height in diameter, and not more than one-fifth of the area should be cut over at any one time. All trees in a clump should be cut or left. In stands with small natural openings—about one tree height in diameter—the openings can be enlarged one tree height by removing clumps of trees to the windward.

Four additional entries into the stand can be made at periodic intervals; but no new entry should be made until the openings cut the previous entry have regenerated. The last groups to be removed should be retained until the original group openings are large enough to provide a seed source or plan on planting the openings created by the last cut. About 20% of the basal area should be removed over about one-fifth of the area at each entry. Group openings should be no larger than one tree height in diameter.

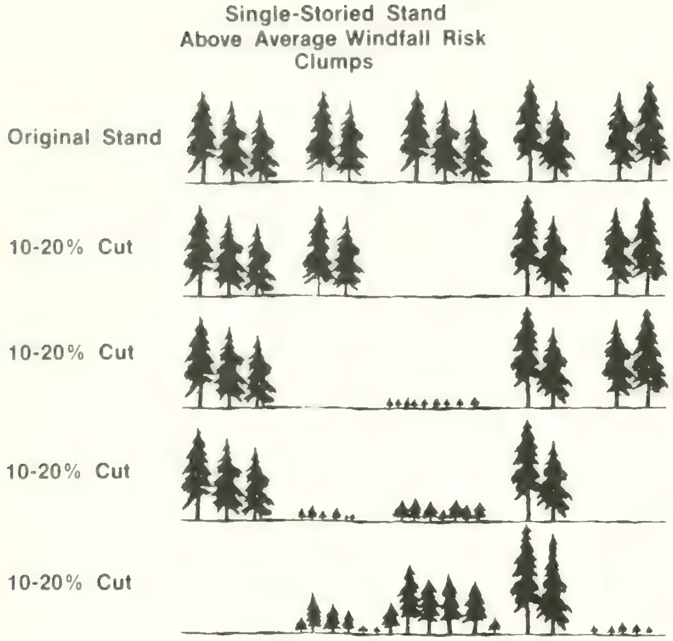


Figure 20.—Sequence of entries with a group shelterwood in a clumpy-spaced, single-storied spruce-fir stand in an above-average wind risk situation.

If windfall risk is very high, the choice is limited to removing all the trees or leaving the area uncut. Cleared openings should not be larger than regeneration requirements dictate, and they should be interspersed with uncut areas of at least equal size. No more than one-third of the total area in this wind risk situation should be cut over at one time.

Two-storied stands.—Stands may appear to be two-aged (fig. 21), but usually contain more than two age classes. Top story (dominants, codominants, and intermediates) is usually spruce, and the stand appears to be single-storied. The second story is often fir; and the trees are younger and smaller in diameter than the overstory. It may consist of small saw logs, poles, or large saplings, but is always below the top story and clearly distinguishable from it. Trees in the second story are overtopped, but not suppressed. There may be a manageable stand of advanced reproduction. Individual trees vary from uniformly spaced to clumpy. Lodgepole pine is absent or sparse.

Recommended cutting treatments are the same as for three-storied stands.

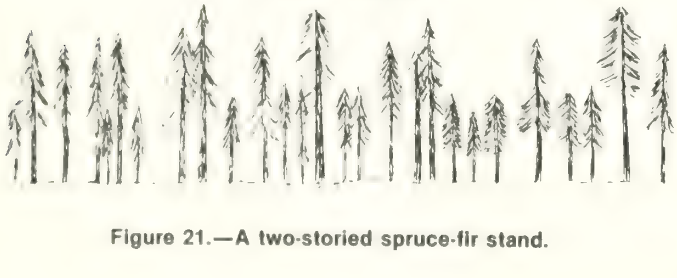


Figure 21.—A two-storied spruce-fir stand.

Three-storied stands.—Stand may appear to be three-aged (fig. 22), but usually contain more than three age classes. Occasionally they are two-aged, but never all-aged.

If the stand is three-aged or more, the top story is predominantly spruce and resembles an open-grown single-storied stand. Second and third stories usually are composed of younger and smaller trees, predominately fir. In a typical stand, the second story will be 10 to 30 feet below the top story, and the third story will be 10 to 30 feet below the second story. Although the second and third stories are overtopped, trees are usually not suppressed. If two-aged, the first two stories are old-growth with spruce in the top story and fir in the second story. The third story will be younger trees, largely fir of smaller diameter. The stand may be a manageable stand of advanced reproduction. It is more often clumpy than uniformly spaced. Lodgepole pine is usually absent or sparse.

Trees in the overstory of two- and three-storied stands usually are more windfirm than those in single-storied stands. The second and third stories are likely to be less windfirm than the top story.

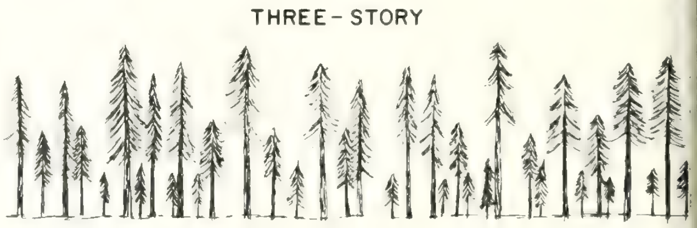


Figure 22.—A three-storied spruce-fir stand.

If windfall risk is low, and trees are uniformly spaced, the first cut removes about 40% of the basal area (fig. 23). This cutting is heavy enough to be the seed cut of a two-step shelterwood; but the marking follows the rules for individual tree selection—mature trees are removed from each story. Because the overstory is likely to be more windfirm, selected dominants and codominants of good vigor and free of defect should be left as a seed source. Avoid cutting holes in the canopy larger than one tree height in diameter by distributing the cut over the entire area. Do not remove dominant trees from the interior of the stand that are protecting other trees to their leeward if these latter trees are to be reserved for the next cut.

The second entry is the final harvest to remove the remaining stand and release the reproduction. It cannot be made until the new stand of reproduction is established. If the residual volume is greater than about 10,000 fbm per acre, the final harvest should be made in two stages ("stage logging") to avoid undue damage to new reproduction. The second stage can begin as soon as the skidding is finished in the first.

If there is a manageable stand of advanced reproduction and the volume is not too heavy, the first cut can be simulated shelterwood that removes the overstory. Otherwise, the first cut should remove 40% of the basal area on an individual tree basis as long as the more wind-

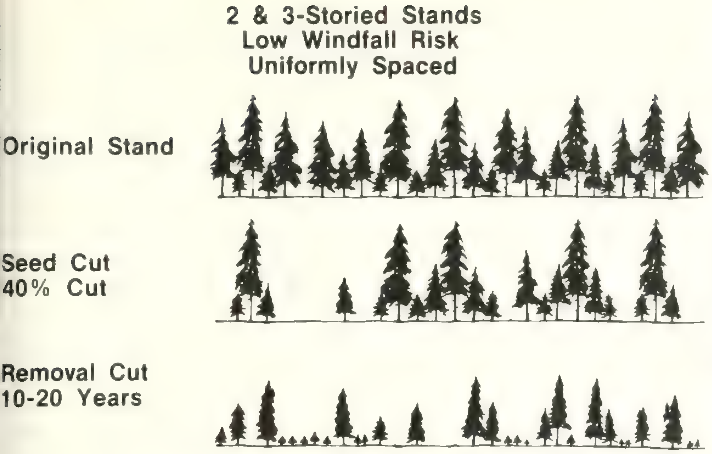


Figure 23.—Sequence of entries with a two-cut shelterwood in a uniformly-spaced, two- or three-storied spruce-fir stand in a low wind risk situation.

firm dominants and codominants are left. The timing of the second cut is not critical from a regeneration standpoint, provided that a manageable stand of reproduction still exists after the first cut.

The manager has other options to choose from, including cutting less than the recommended basal area, making more entries, and spreading the cut out over time by delaying the final harvest until the new stand is tall enough to create a continuous high forest. Another option is to convert these stands to an uneven-aged structure by making a series of light cuts—10% to 20% of the basal area—at frequent intervals—10 to 20 years. Ultimately the stand will contain a series of age classes.

If windfall risk is low, and trees are clumpy (fig. 24), the first cut should remove about 40% of the basal area in a group shelterwood. Openings can be larger (two or three times tree height) than for single-storied stands; but the area cut over should be not more than one-third of the total. Group openings should be irregular in shape, but without dangerous windcatching indentations in the edges. All trees in a clump either should be cut or left.

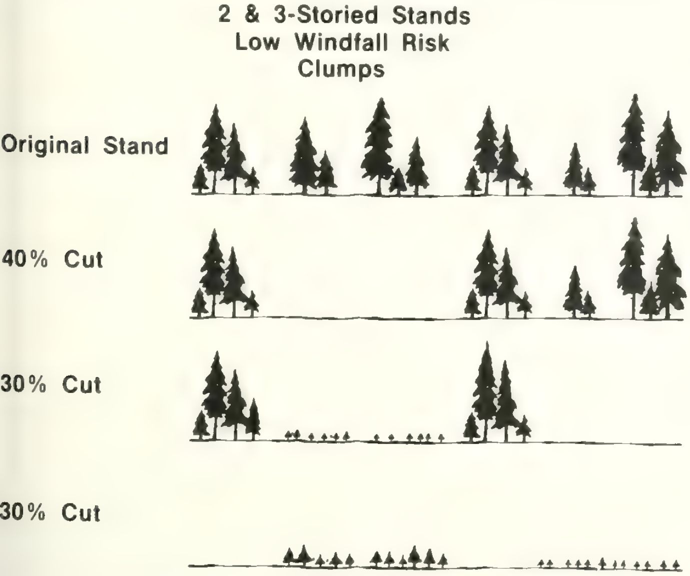


Figure 24.—Sequence of entries with a group shelterwood in a clumpy-spaced, two- or three-storied spruce-fir stand in a low wind risk situation.

Two additional entries can be made. They should each remove about 30% of the original basal area in group openings up to two to three times tree height; but not more than one-third of the area should be cut over at any one time. If there is not a manageable stand of advanced reproduction, the manager must wait until the first group of openings is regenerated before cutting the second series. Also, the cutting of the final groups until there is a seed source either must be delayed or these openings must be planted. If there is a manageable stand of advanced reproduction, the timing between cuts is not critical for regeneration.

The manager has the option of removing less than the recommended basal area and cutting less than the recommended area at any one time. This will require more entries and spread the cut over time.

If windfall risk is above average, and trees are uniformly spaced (fig. 25), and if these stands do not contain a manageable stand of reproduction, the first entry should be a preparatory cut that removes up to 20% of the basal area on an individual tree basis. Predominants, intermediates with long dense crowns, and trees with known indicators of defect should be removed first; but the general canopy level should be maintained. The objective of this cut is to open up the stand, and at the same time minimize the windfall risk to remaining trees. Provision should be made to salvage postharvest windfalls after spruce beetle flight in July.

The second entry into the stand should be made in about 10 years. It will remove about 40% of the basal area, including the salvage of any windfalls that occur between the first and second cuts. During this seed cut, the best dominants and codominants should be reserved as a seed source; but it is important to distribute the cut over the entire area.

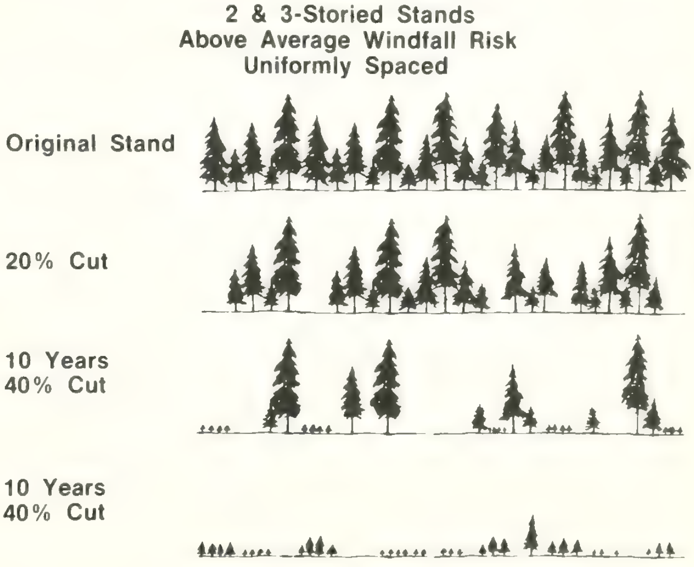


Figure 25.—Sequence of entries with a shelterwood in a uniformly-spaced, two- or three-storied spruce-fir stand in an above-average wind risk situation.

The next entry is the final harvest to remove the remaining merchantable volume and release the reproduction. If the residual stand has too heavy a volume, the final harvest should be made in two steps.

If these stands contain a manageable stand of reproduction and the volume per acre is not too heavy, the first cut can be a simulated shelterwood that removes the overstory. If the volume is too heavy for a one-stage removal, the manager should follow the preceding recommendations, because the wind risk is too great to permit a two-stage removal in a stand that has not been previously opened up.

If windfall risk is above average, and trees are clumpy, the first cut should be a group shelterwood that removes about 25% of the basal area (fig. 26). Openings should be kept small—not more than one or two tree heights in diameter—and not more than one-fourth of the area should be cut over at any one time. All trees in a clump should either be cut or left. Small natural openings can be enlarged one or two tree heights by removing trees in clumps to windward of the opening.

Three additional entries should be made. About 25% of the original basal area should be removed on about one-fourth of the area in each entry. The interval between cuts will depend upon the time required to regenerate each series of openings. The manager must either delay the removal of the final groups until a seed source is available or plant the openings.

If the windfall risks are very high, the choice usually is limited to removing all the trees or leaving the area uncut. Cleared openings should not be larger than regeneration requirements dictate, and should be interspersed with uncut areas. Not more than one-third of the total area in this windfall risk situation should be cut over at any one time.

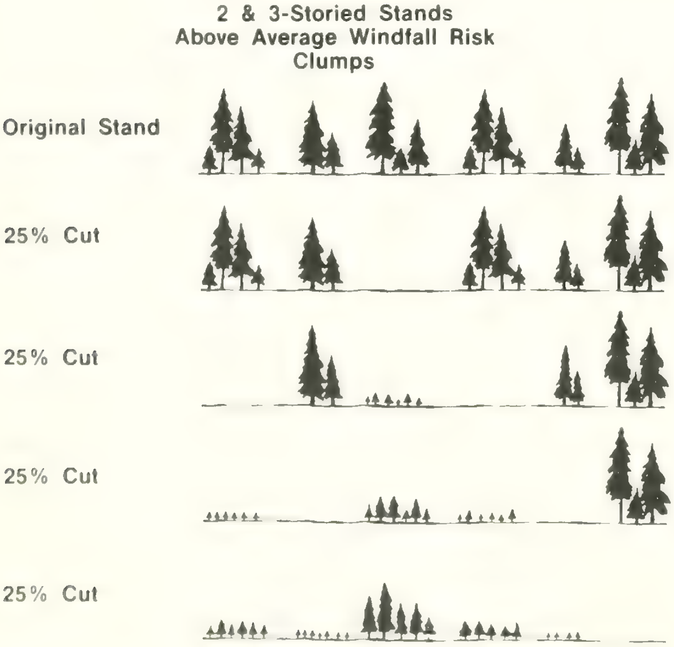


Figure 26.—Sequence of entries with a group shelterwood in a clumpy-spaced, two- or three-storied spruce-fir stand in an above-average wind risk situation.

Multi-storied stands.—These stands are generally uneven-aged (fig. 27) with a wide range in diameters. If the stand developed from relatively few individuals, the overstory trees are coarse limbed, and fill-in trees are finer limbed. Overstory trees may be relatively vigorous. If the stand developed from the deterioration of a single- or two-storied stand, the overstory may be no limbier than fill-in trees. Much of the vigorous growing stock is below saw log size. There is almost always a manageable stand of reproduction. Fill-in trees may be clumpy, but overstory trees are usually uniformly spaced. Lodgepole pine may occur as a scattered component of all stories. These usually are the most windfirm stands even where they have developed from the deterioration of single- and two-storied stands, because by the time they have reached their present condition the remaining overstory trees are usually windfirm.

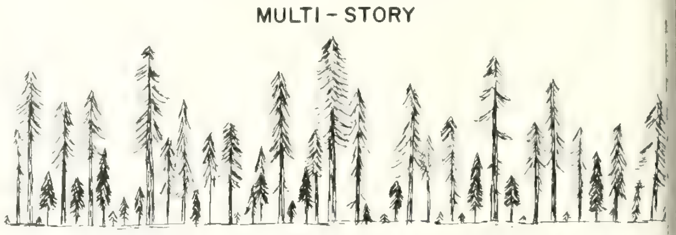


Figure 27.—A multi-storied spruce-fir stand.

If windfall risk is low, there is considerable flexibility in harvesting these stands. All size classes can be cut with emphasis on either the largest or smallest trees in the stand. For example, the first cut can range from removal of all large trees in the overstory to release the younger growing stock, to a thinning from below to improve the spacing of the larger trees (fig. 28). If the manager elects to make a simulated shelterwood that removes the overwood and the volume is too heavy, it should be harvested in two stages. Cutting can then be directed toward either even- or uneven-aged management, with entries made as often as growth and regeneration needs dictate. If the manager elects to make a thinning from below, management of the stand is usually directed toward even-aged management.

If the windfall risk is above average or very high, the safest first cut is a simulated shelterwood that removes the overwood with a thinning from below to obtain a widely spaced, open-grown stand that will be windfirm (fig. 29). Cutting can then be directed toward either even- or uneven-aged management.

Modifications to cutting treatments imposed by spruce beetles.—If spruce beetles are present in the stand at an endemic level, or in adjacent stands in sufficient numbers to make successful attacks, and less than the recommended percentage of basal area to be removed is in susceptible trees, any attacked and all susceptible trees should be removed in the first cut. This will include most of the larger spruce trees and is a calculated risk, especially in above-average wind risk situations. Furthermore, the percentage of fir in the stand will increase. Provision should be made to salvage attacked trees. The remaining cuts should be scheduled in accordance with windfall risk, insect susceptibility, and regeneration needs (Alexander 1974).

If, in these stands, more than the recommended perentage of basal area to be removed is in susceptible rees, the manager has three options: (1) remove all the usceptible trees, (2) remove the recommended basal area n attacked and susceptible trees and accept the risk of uture losses, or (3) leave the stand uncut. If the stand s partially cut or left uncut, surviving spruce would proably make up at least 50% of the residual basal area; ut most of the merchantable spruce would be small-iameter trees (Alexander 1974).

If the stand is sustaining an infestation that is building p and the manager chooses to either partially cut or eave the stand uncut because clearcutting is unaccepable, there is a risk of an outbreak that will destroy most f the merchantable spruce in the stand and spread to djacent stands (Alexander 1974).

Cutting to save the residual stand.—In shelterwood utting, protection of the residual stand from logging lamage is a primary concern. The residual stand inludes merchantable trees left after standard shelterwood nd reproduction established after the seed cut in standrd shelterwood, and reproduction established after each ut in group shelterwood. Before the final harvest is nade with standard shelterwood, and before each enry with group shelterwood, the manager must determine f there is an acceptable stand of reproduction. Furthernore, the stand must be reevaluated after final harvest n standard shelterwood and after each entry with group helterwood to determine the need for supplemental tocking. The same criteria used to evaluate advanced eproduction with a simulated shelterwood applies here.

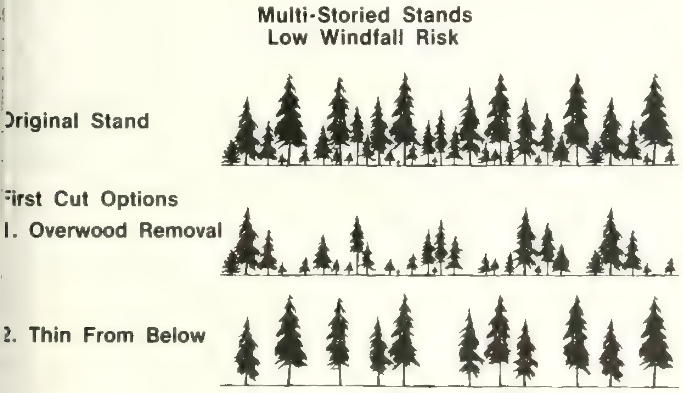


Figure 28.—Options for the first entry into a multistoried spruce-fir stand in a low wind risk situation.

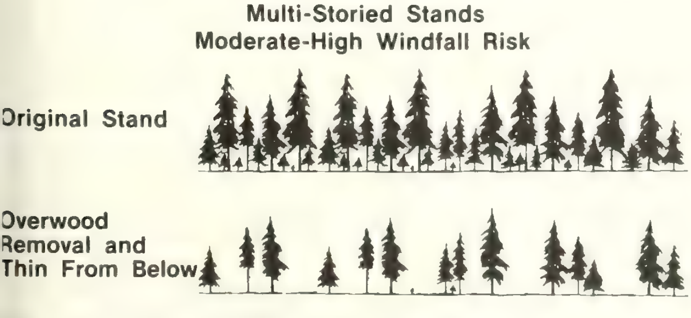


Figure 29.—First entry into a multi-storied spruce-fir stand in an above average to high wind risk situation.

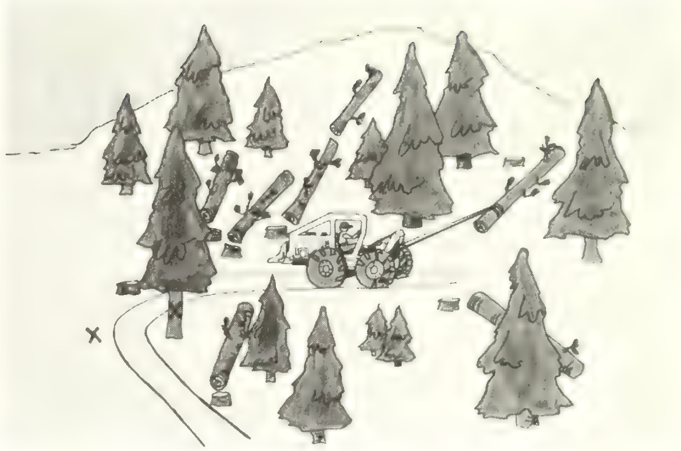


Figure 30.—Schematic drawing of layout of skidroads and felling patterns.

Protection begins with a well-designed logging plan at the time of the first cut. To minimize damage, the same protection measures suggested for simulated shelterwood apply here (fig. 30).

Slash disposal and seedbed preparation.—Some slash disposal probably will be needed after each cut; but it should be confined to concentrations and reduction of visual impact, because most equipment now available for slash disposal is not readily adaptable to working in shelterwood cuttings. Furthermore, burning slash will cause additional damage to the residual stand. Skid out as much of the downed sound dead and green cull material as possible for disposal at the landings or at the mill. Some hand piling or scattering may be needed where slash disposal equipment cannot be used. In group shelterwood cutting, if a manageable stand of reproduction has not been established, dozers equipped with brush blades can be used to concentrate slash for burning in the openings. Piles should be kept small to reduce the amount of heat generated. Leave some of the larger pieces of slash and other debris in place to provide shade for new seedlings. Cut green spruce material larger than 8 inches in diameter should be removed to reduce the buildup of spruce beetle populations (Alexander 1974).

On areas to be regenerated, a partial overstory canopy of trees standing around the margins of small openings provide two of the basic elements necessary for regeneration success—a seed source within effective seeding distance, and an environment compatible with germination, initial survival, and seedling establishment. The manager must make sure that the third element—a suitable seedbed—is provided after the seed cut where standard shelterwood cutting is used, and after each cut where group shelterwood is used. If at least 40% of the available ground surface is not exposed mineral soil after logging and slash disposal, additional seedbed preparation is needed. Until special equipment is developed, the same problem exists as with slash disposal. The equipment currently available is too large to work well around standing trees. Smaller machines equipped with suitable attachments will have to be used (Alexander 1974).

UNEVEN-AGED CUTTING METHODS

Multi- and three-storied spruce-fir stands frequently are uneven- to broad-aged or have the diameter distribution normally associated with uneven-aged stands. Although uneven-aged cutting methods—individual tree and group selection—seldom have been used in spruce-fir forests, they appear to simulate the natural dynamics of these forests. Moreover, uneven-aged management is more compatible or desirable for some management objectives or resource needs. For example, the impact on the forest should be as light as possible in areas of erosive soils, or where management goals include maintenance of continuous high forests. Uneven-aged management often is more appropriate for these conditions and objectives.

Uneven-aged management includes cultural treatments, thinnings, and harvesting necessary to maintain continuous high forest cover, provide for regeneration of desirable species, either continuously or at each harvest, and provide for controlled growth and development of trees through the range of size classes needed for sustained yield of forest products. Managed uneven-aged stands are characterized by trees of many sizes intermingled singly or in groups. Cutting methods do not produce stands of the same age that are large enough to be recognized as a stand. Forests are subdivided into recognizable units that can be located on the ground on the basis of timber type, site, logging requirements, etc., rather than acreage in stand-age classes. Regulation of growing stock is accomplished by setting: (1) a residual stocking goal, in terms of basal area or volume, that must be maintained to provide adequate growth and yield, (2) a diameter distribution goal that will provide for regeneration, growth and development of replacement trees, and (3) a maximum tree size goal. In addition, a decision must be made on how to handle small trees. The procedures described here are for initial entry into unregulated old-growth spruce-fir stands that are to be converted to managed uneven-aged stands using either individual-tree or group selection cutting.

Individual Tree Selection Cutting

This regeneration cutting method harvests trees in several or all diameter classes on an individual basis. Stands regenerate continuously. The ultimate objective is to provide a stand with trees of different sizes and age classes intermingled on the same site (USDA Forest Service 1983). Choice of trees to be cut depends on their characteristics and relationship to stand structure goals set up to regulate the cut. This cutting method provides maximum flexibility in choosing trees to cut or leave, and is appropriate only in uniformly spaced stands with irregular to all-aged structure. Individual-tree selection cutting favors fir over spruce; and in mixed spruce-fir-lodgepole pine stands, few intolerant pines become established after initial cutting (Alexander and Edminster 1977b).

Group Selection Cutting

This regeneration cutting method harvests trees in groups, ranging from a fraction of an acre up to about 2 acres (USDA Forest Service 1983). This cutting method is similar to a group shelterwood except in the way the growing stock is regulated. The area cut is smaller than the minimum feasible for a single stand under even-aged management. Trees are marked on an individual-tree basis; but emphasis is on group characteristics, which means trees with high potential for future growth are removed along with trees with low growth potential. Loss in flexibility is partly offset by the opportunity to uniformly release established regeneration and reduce future logging damage. When groups are composed of only a few trees, the method can be used together with individual-tree selection cutting. This cutting method is most appropriate in irregular to all-aged stands that are clumpy or groupy. However, it can be used in uniformly spaced stands with the size, shape, and arrangement of openings based on factors other than the natural stand conditions (Alexander and Edminster 1977a, 1977b).

Stand Structure Goals

Control of Stocking

The first step in applying a selection cut to a spruce-fir stand is to determine the residual stocking level to be retained. Because total stand growth for many species adapted to uneven-aged management does not differ greatly over the range of stocking levels likely to be management goals, stocking levels set near the lower limit, where no growth is lost, concentrate increment on fewest stems. This reduces time required to grow individual trees to a specific size, and requires a minimum investment in growing stock (Alexander and Edminster 1977b).

The residual stocking level with the best growth in spruce-fir stands varies with species composition, management objectives, productivity, diameter distribution, etc. In unregulated old-growth spruce-fir stands with irregular structure, stocking usually varies from 150 to 300 square feet of basal area per acre in trees in the 4-inch and larger diameter classes (Alexander 1985a, Alexander et al. 1982). Basal areas above 200 square feet per acre probably represent overstocking. While no guidelines are available for uneven-aged stands, residual stocking levels of GSL 100 to GSL 180 are suggested for managed even-aged stands, depending on site productivity, number of entries, and other management objectives (Alexander and Edminster 1980). These levels should be useful in estimating initial residual stocking goals in terms of square feet of basal area per acre for that part of the stand that eventually will be regulated under uneven-aged management (Alexander and Edminster 1977b).

While these general recommendations are probably adequate to start with, use of yield tables for even-aged spruce-fir stands in setting stocking goals for uneven-aged stands assumes there is little difference between the growing stock of the two, other than a redistribution of age classes over a smaller area (Bond 1952). This may be true when stands without a manageable understory of advanced growth are harvested by a group selection method. The result is likely to be a series of small, even-aged groups represented in the same proportion as a series of age classes in even-aged management. If advanced growth of smaller trees has become established under a canopy of larger trees, however, a different structure may develop with either individual-tree or group selection systems. Growing space occupied by each age or size class is being shared (Reynolds 1954). Assuming that damage to understory trees resulting from removal of part of the overstory trees can be minimized, advanced growth will successfully establish a series of age classes on some areas. In this situation, more trees of a larger size can be grown per acre than with a balanced even-aged growing stock (Bourne 1951, Meyer et al. 1961). Nevertheless, without better information, the residual stocking goals set for even-aged management are the best criteria available.

Maximum Tree Size

The second item of information needed is the maximum diameter of trees to be left after cutting. In old-growth spruce-fir stands, maximum diameter usually varies from 18 to 30 inches d.b.h., depending on stand density, site quality, species composition, etc. Examination of plot inventory information from unmanaged stands with irregular stand structure, suggests that a diameter of 24 inches can be attained within the time period generally considered reasonable under a wide range of site quality and stocking conditions. In the absence of any information on growth rates in uneven-aged stands, or rates of return for specific diameter and stocking classes, a 24-inch maximum diameter seems a reasonable first approximation to set for timber production. Trees of larger diameter with a lower rate of return on investment may be appropriate for multiple-use reasons (Alexander and Edminster 1977b).

Control of Diameter Distribution

Control over distribution of tree diameters also is necessary to regulate yields under uneven-aged management. This most important step is accomplished by establishing the desired number of trees or basal area for each diameter class.

When used with flexibility, the quotient q between number of trees in successive diameter classes is a widely accepted means of calculating diameter distrubutions in uneven-aged stands (Meyer 1952). Values of q ranging between 1.3 and 2.0 (for 2-inch diameter classes) have been recommended for various situations. The lower the q, the smaller is the difference in number of trees between diameter classes. Stands maintained at a small q have a higher proportion of available growing stock in larger trees, for any residual stocking level, but may require periodic removal of the largest number of small trees in the diameter class where unregulated growing stock crosses the threshold into the portion of the stand to be regulated (Alexander and Edminster 1977b).

Consider, for example, differences in numbers of small and large trees maintained at a q level of 1.3, 1.5, 1.8 and 2.0 inches in stands with the same residual basal area (100 square feet) (table 1). At all stocking levels considered appropriate for future management goals, many small trees would have to be cut under lower q levels at the threshold diameter class (in this example the 4-inch class). Fewer larger trees would be retained under higher q levels.

In the absence of any experience, data, or good growth and yield information, the best estimate of numbers of trees to leave by diameter classes is to use the lowest q

Table 1.—Residual stand structures for 100 square feet of basal area and maximum tree diameter of 24 inches d.b.h. for various q values. All data are on a per-acre basis (Alexander and Edminster 1977b).

	q = 1.3		q = 1.5		q = 1.8		q = 2.0	
Diameter class (inches)	No. of trees	Basal area (ft.^{2})	No. of trees	Basal area (ft.^{2})	No. of trees	Basal area (ft.^{2})	No. of trees	Basal area (ft.^{2})
4	38.80	3.38	79.08	6.89	156.01	13.62	210.18	18.35
6	29.90	5.87	52.72	10.34	86.68	17.01	105.09	20.63
8	23.02	8.04	35.14	12.26	48.15	16.81	52.54	18.35
10	17.96	9.65	23.43	12.78	26.75	14.59	26.27	14.33
12	13.62	10.69	15.62	12.26	14.86	11.67	13.14	10.32
14	10.47	11.20	10.41	11.12	8.26	8.83	6.57	7.02
16	8.07	11.26	6.95	9.70	4.59	6.41	3.28	4.58
18	6.21	10.97	4.63	8.18	2.55	4.50	1.64	2.90
20	4.77	10.41	3.08	6.73	1.42	3.09	0.82	1.79
22	3.67	9.68	2.06	5.42	0.79	2.08	0.41	1.08
24	2.82	8.86	1.37	4.30	0.44	1.37	0.20	0.64
Total	159.14	100.01	234.49	99.98	350.50	99.98	420.14	99.99

value that is reasonable in terms of existing markets, stand conditions, and funds available for cultural work. Examination of plot data from a wide range of old-growth spruce-fir stands indicates that pretreatment distributions are likely to range between 1.3 and 1.8 for 2-inch classes. As a general recommendation, q levels between 1.3 and 1.5 appear to be reasonable initial goals for the first entry into unmanaged stands (Alexander and Edminster 1977b).

How to Determine Residual Stand Structure

Once goals for residual stocking, maximum tree diameter, and q levels have been selected, the specific structure for a stand can be calculated, provided that data are available to construct a stand table (Alexander and Edminster 1977b).

Two existing old-growth spruce-fir stands on the San Juan National Forest in Colorado are used to illustrate the procedure (stands A and B). The actual inventory data for stand A are shown in columns 1, 2, and 3 of table 2. A residual basal area of 80 square feet per acre in trees 3.0 inches in diameter and larger was chosen because: (1) it allows maximum reduction (30%) in present basal area consistent with previously developed recommendations for minimizing blowdown after partial cutting (Alexander 1973), and (2) it is the lowest basal area that appears to be a realistic timber management goal in spruce-fir stands. A maximum tree diameter of 24 inches d.b.h. was chosen, because it also appears to be a realistic goal to be attained in a reasonable period of time. Finally, a q of 1.5 was chosen, because it approximates the q in the natural stand, and does not require removal of many small trees. A lower q may be feasible; but it would require heavy cutting in lower diameter classes.

To determine the residual stand goal, the value of th residual density parameter k corresponding to a bas area of 80 square feet must be calculated. Values neec ed for this computation with a q of 1.5 are given in co umn 6 of table 3. The value of k is computed as

$$k = \frac{80.0}{0.57682 - 0.01454} = 142.2779$$

where 80.0 is the desired basal area per acre, 0.5768 is the table value for the desired maximum tree diamete class of 24 inches, and 0.01454 is the table value for th 2-inch class. Note that the value for the 2-inch class i subtracted from the 24-inch class value, because tree smaller than the 4-inch class are not considered in th management guidelines. Desired residual number c trees in each diameter class (column 4 of table 2) can b directly calculated by multiplying the proper diamete class values given in column 6 of table 4 by the valu of k. The desired residual basal area in each diamete class (column 5 of table 2) can be calculated by multipl ing the residual number of trees in each diameter clas by the tree basal area given in table 5.

Comparing actual and desired diameter distribution shows where deficits and surpluses occur (fig. 31). T bring this stand under management, the number of tree should be allowed to increase in the diameter classes th are below the idealized stocking curve, with cuttin limited to those diameter classes with surplus trees. A a guide, enough trees should be left above the curve i surplus diameter classes to balance the deficit in tree in diameter classes below the curve. In this example, a surplus trees will be cut in the 6- to 14-inch diamete classes, and in the 24- and 26-inch classes; no trees wi be cut in the other classes. The final stand structure i shown in figure 32 and columns 6 and 7 of table 2. Co umns 8 and 9 show the trees and basal area removed

Table 2.—Actual stand conditions and management goals for stand A using basal area as the density measure. All data on a per acre basis—stand goals; q = 1.5, residual basal area = 80 square feet; maximum tree diameter of 24 inches d.b.h. (Alexander and Edminster 1977b).

	Actual stand		Residual stand goal		Final stand		Cut	
Diameter class (inches) (1)	No. of trees (2)	Basal area (ft.²) (3)	No. of trees (4)	Basal area (ft.²) (5)	No., of trees (6)	Basal area (ft.²) (7)	No., of trees (8)	Basal area (ft.²) (9)
4	57	4.97	63.23	5.52	57.0	4.98	0	0
6	53	10.41	42.16	8.28	42	8.24	11	2.16
8	46	16.06	28.10	9.81	28	9.77	18	6.28
10	32	17.45	18.74	10.22	19	10.36	13	7.09
12	16	12.57	12.49	9.81	12.5	9.81	3.5	2.75
14	14	14.97	8.33	8.90	8.5	9.09	5.5	5.88
16	6	8.38	5.55	7.75	6	8.38	0	0
18	3	5.30	3.70	6.54	3	5.30	0	0
20	5	10.91	2.47	5.39	5	10.91	0	0
22	0	0	1.64	4.33	0	0	0	0
24	2	6.28	1.10	3.46	1	3.14	1	3.14
26	2	7.37	—	—	—	—	2	7.37
Total	236	114.67	187.51	80.01	182	79.98	54	34.67

Table 3.—Values needed to compute k for different q ratios and diameter ranges using basal area as the density measure (Alexander and Edminster 1977b).

2-inch diameter classes (1)	q ratio 1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)	1.6 (7)	1.7 (8)	1.8 (9)	1.9 (10)	2.0 (11)
2	0.01983	0.01818	0.01678	0.01558	0.01454	0.01364	0.01283	0.01212	0.01148	0.01091
4	.09196	.07878	.06842	.06011	.05333	.04772	.04303	.03905	.03566	.03273
6	.23948	.19241	.15779	.13166	.11151	.09566	.08300	.07272	.06428	.05727
8	.47790	.36075	.28001	.22253	.18046	.14893	.12479	.10597	.09107	.07909
10	.81656	.57994	.42691	.32394	.25228	.20094	.16320	.13484	.11310	.09613
12	1.25990	.84297	.58963	.42825	.32124	.24775	.19574	.15793	.12979	.10840
14	1.80848	1.14132	.75999	.52966	.38380	.28758	.22179	.17539	.14175	.11675
16	2.45985	1.46605	.93116	.62428	.43828	.32009	.24181	.18806	.14997	.12221
18	3.20930	1.80854	1.09780	.70981	.48425	.34580	.25671	.19697	.15545	.12566
20	4.05043	2.16089	1.25606	.78523	.52209	.36565	.26753	.20308	.15901	.12779
22	4.97568	2.51618	1.40336	.85042	.55261	.38065	.27524	.20719	.16127	.12908
24	5.97669	2.86853	1.53820	.90583	.57682	.39181	.28063	.20991	.16269	.12985
26	7.04470	3.21314	1.65994	.95229	.59576	.40000	.28435	.21168	.16357	.13030
28	8.17072	3.54619	1.76854	.99077	.61041	.40593	.28689	.21282	.16410	.13056
30	9.34585	3.86479	1.86444	1.02232	.62162	.41019	.28861	.21354	.16443	.13071
32	10.56133	4.16688	1.94837	1.04797	.63012	.41322	.28975	.21400	.16462	.13079
34	11.80875	4.45107	2.02126	1.06864	.63652	.41536	.29052	.21429	.16474	.13084
36	13.08011	4.71658	2.08412	1.08520	.64131	.41685	.29102	.21447	.16480	.13087

Table 4.—Values needed to compute desired number of residual trees for different q ratios (Alexander and Edminster 1977b).

2-inch diameter classes (1) D_i	q ratio 1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)	1.6 (7)	1.7 (8)	1.8 (9)	1.9 (10)	2.0 (11)
2	0.909091	0.833333	0.769231	0.714286	0.666667	0.625000	0.588235	0.555556	0.526316	0.500000
4	.826446	.694444	.591716	.510204	.444444	.390625	.346021	.308642	.277008	.250000
6	.751315	.578704	.455166	.364431	.296296	.244141	.203542	.171468	.145794	.125000
8	.683013	.482253	.350128	.260308	.197531	.152588	.119730	.095260	.076734	.062500
10	.620921	.401878	.269329	.185934	.131687	.095367	.070430	.052922	.040386	.031250
12	.564474	.334898	.207176	.132810	.087791	.059605	.041429	.029401	.021256	.015625
14	.513158	.279082	.159366	.094865	.058528	.037253	.024370	.016334	.011187	.007813
16	.466507	.232568	.122589	.067760	.039018	.023283	.014335	.009074	.005888	.003906
18	.424098	.193807	.094300	.048400	.026012	.014552	.008433	.005041	.003099	.001953
20	.385543	.161506	.072538	.034572	.017342	.009095	.004960	.002801	.001631	.000977
22	.350494	.134588	.055799	.024694	.011561	.005684	.002918	.001556	.000858	.000488
24	.318631	.112157	.042922	.017639	.007707	.003553	.001716	.000864	.000452	.000244
26	.289664	.093464	.033017	.012599	.005138	.002220	.001010	.000480	.000238	.000122
28	.263331	.077887	.025398	.008999	.003425	.001388	.000594	.000267	.000125	.000061
30	.239392	.064905	.019537	.006428	.002284	.000867	.000349	.000148	.000066	.000031
32	.217629	.054088	.015028	.004591	.001522	.000542	.000206	.000082	.000035	.000015
34	.197845	.045073	.011560	.003280	.001015	.000339	.000121	.000046	.000018	.000008
36	.179859	.037561	.008892	.002343	.000677	.000212	.000071	.000025	.000010	.000004

Similar goals can be calculated using crown competiion factor (CCF) as the density measure. Actual stand nventory data are shown in columns 1, 2, and 3 of table . Again, assuming a 30% reduction in stand density, the esidual CCF should be 55.8. Data from column 6 of table provides the following value of k:

$$k = \frac{55.8}{0.45417 - 0.04920} = 137.7880.$$

The value of k is then used to compute the residual number of trees and maximum crown area (MCA) values (columns 4 and 5 in table 6). Computations are similar to the previous method using basal area, except that a slightly different k value, and tree MCA values are used. The final stand structure and trees to be cut are shown in columns 6 through 9 in table 6.

It is not likely that unregulated stands will be brought under control with one cut or even a series of cuts. More likely, limitations imposed by stand conditions, windfall, and insect susceptibility will result in either over- or undercutting spruce-fir stands, at least at the first entry. Another example illustrates this, using information from

Table 5.—Values of tree basal area (in square feet) and maximum crown area (MCA) (in percent of an acre), by diameter (Alexander and Edminster 1977b).

2-inch diameter class	Basal area	MCA
2	0.022	0.074
4	.087	.129
6	.196	.199
8	.349	.284
10	.545	.385
12	.785	.501
14	1.069	.632
16	1.396	.778
18	1.767	.939
20	2.182	1.116
22	2.640	1.308
24	3.142	1.515
26	3.687	1.737
28	4.276	1.974
30	4.909	2.227
32	5.585	2.495
34	6.305	2.778
36	7.069	3.076

another stand on the San Juan National Forest (stand B). Actual stand inventory data are shown in columns 1, 2, and 3 in table 8. A residual basal area of 120 square feet per acre in trees 3.0 inches in diameter and larger would be a desirable stocking level, based on previous assumptions. This would be too heavy a cut, however, because it would open up the stand to possible damage from wind and subsequent loss to spruce beetles. With 223 square feet of basal area per acre in the stand, an initial reduction to 150 square feet per acre in trees 3.0 inches in diameter and larger would be appropriate. A q of 1.5 an a maximum tree diameter of 24 inches again wer selected for the same reasons as in the first example. Procedures used to obtain columns 4 and 5 in table 8 ar also the same as before (table 2).

A comparison of curves of actual desired diamete distributions shows where deficits and surpluses occu (fig. 33). In this example, the bulk of trees removed com from the 14- to 20-inch diameter classes; but no mor than 50% of the trees would be removed in the larges diameter classes. Few or no trees would be cut in th smaller diameter classes. The final stand structure i shown in figure 34 and columns 6 and 7 in table 8.

How to Handle Small Trees

The threshold diameter class also must be determined Calculations often are made down to the 4-inch diamete class by 2-inch classes, because there are usually man small trees in spruce-fir stands that are below minimur merchantable diameter. They compete with larger stem for growing space. More important, these trees provid ingrowth into merchantable size classes needed to prac tice individual-tree selection silviculture.

Although small trees should not be ignored in inventory and record keeping, it may be neither desirable no possible to regulate the number of them. In spruce-fi forests in the central Rocky Mountains, minimum merchantable diameter is usually 7 to 8 inches. Regulatio of the number of trees below this size requires an investment in silvicultural work that may not be recapture under current market conditions. However, if tree below minimum merchantable size are left unregulated cutting must always be heavy in the threshold diamete

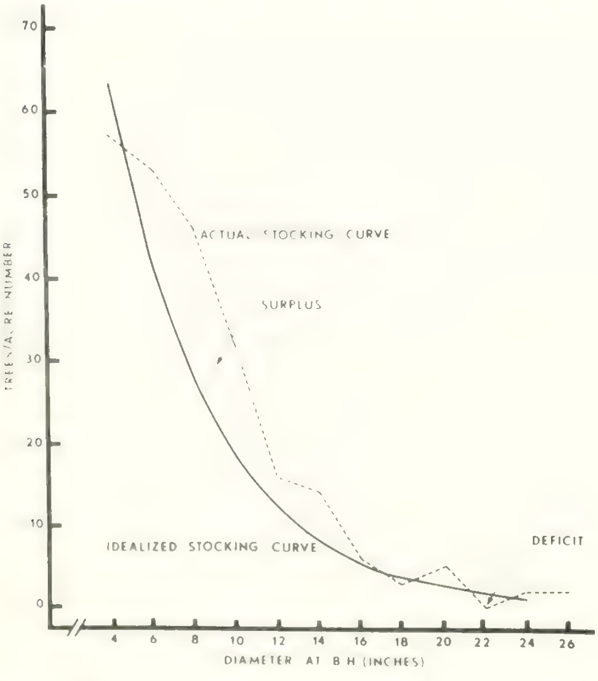


Figure 31.—Actual stocking curve of stand A from inventory data and the idealized stocking curve based on stand structure goals.

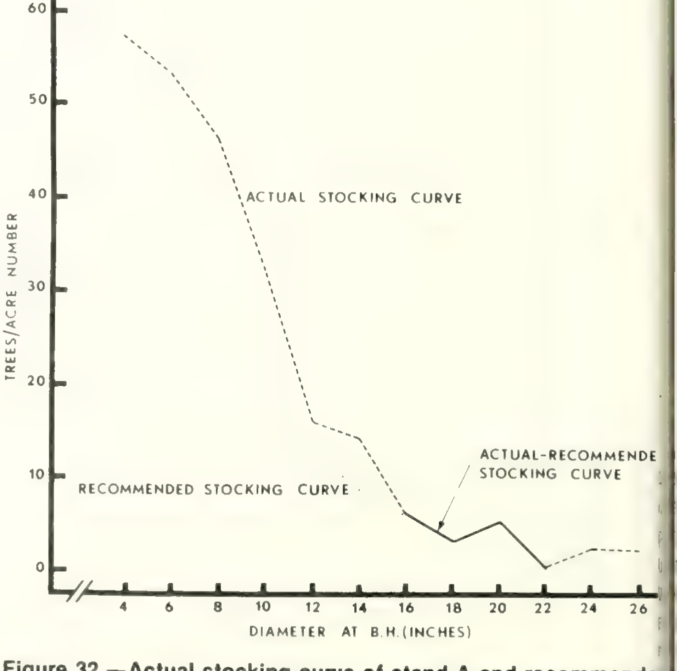


Figure 32.—Actual stocking curve of stand A and recommende stocking curve based on stand structure goals, actual stand stru ture, and management and silvicultural constraints.

Table 6.—Actual stand conditions and management goals for stand A using crown competition factor (CCF) as the density measure. All data are on a per acre basis (Alexander and Edminster 1977b).

Diameter class (inches) (1)	Actual stand: No. of trees (2)	Actual stand: Total MCA (3)	Residual stand goal: No. of trees (4)	Residual stand goal: Total MCA (5)	Final stand: No. of trees (6)	Final stand: Total MCA (7)	Cut: No. of trees (8)	Cut: Total MCA (9)
		CCF		CCF		CCF		CCF
4	57	7.35	61.24	7.90	57	7.35	0	0
6	53	10.55	40.83	8.13	41	8.16	12	2.39
8	46	13.06	27.22	7.73	27	7.67	19	5.39
10	32	12.32	18.14	6.98	18	6.93	14	5.39
12	16	8.02	12.10	6.06	12	6.01	4	2.01
14	14	8.85	8.06	5.09	8	5.09	6	3.76
16	6	4.67	5.38	4.19	6	4.67	0	0
18	3	2.82	3.58	3.36	3	2.82	0	0
20	5	5.58	2.39	2.67	5	5.58	0	0
22	0	0	1.59	2.08	0	0	0	0
24	2	3.30	1.06	1.61	1	1.52	1	1.51
26	2	3.47	—	—	—	—	2	3.47
Total	236	79.72	181.59	55.80	178	55.80	54	23.92

Table 7.—Values needed to compute k for different q ratios and diameter ranges using crown competition factor (CCF) as the density measure (Alexander and Edminster 1977b).

2-inch diameter classes (1)	q ratio 1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)	1.6 (7)	1.7 (8)	1.8 (9)	1.9 (10)	2.0 (11)
2	0.06709	0.06150	0.05677	0.05271	0.04920	0.04612	0.04341	0.04100	0.03884	0.03690
4	.17354	.15094	.13298	.11843	.10644	.09644	.08798	.08075	.07452	.06910
6	.32305	.26611	.22356	.19095	.16541	.14502	.12848	.11488	.10353	.09397
8	.51730	.40326	.32314	.26498	.22159	.18842	.16254	.14197	.12536	.11175
10	.75635	.55798	.42683	.33657	.27228	.22513	.18965	.16234	.14091	.12378
12	1.03904	.72570	.53058	.40308	.31625	.25498	.21040	.17707	.15155	.13161
14	1.36325	.90202	.63127	.46301	.35323	.27852	.22580	.18739	.15862	.13654
16	1.72620	1.08296	.72664	.51573	.38358	.29663	.23695	.19445	.16320	.13958
18	2.12459	1.26502	.81523	.56120	.40802	.31030	.24487	.19918	.16611	.14142
20	2.55486	1.44526	.89618	.59978	.42737	.32045	.25041	.20231	.16793	.14251
22	3.01324	1.62128	.96916	.63208	.44249	.32789	.25422	.20434	.16905	.14314
24	3.49590	1.79117	1.03417	.65879	.45417	.33327	.25682	.20565	.16974	.14351
26	3.99905	1.95352	1.09152	.68068	.46309	.33713	.25858	.20649	.17015	.14373
28	4.51897	2.10730	1.14167	.69845	.46986	.33987	.25975	.20701	.17040	.14385
30	5.05209	2.25184	1.18518	.71276	.47494	.34180	.26053	.20734	.17054	.14391
32	5.59503	2.38678	1.22267	.72422	.47874	.34315	.26104	.20755	.17063	.14395
34	6.14461	2.51199	1.25478	.73333	.48156	.34409	.26137	.20768	.17068	.14397
36	6.69785	2.62752	1.28213	.74053	.48364	.34474	.26159	.20775	.17071	.14399

lasses to bring ingrowth trees down to the desired umber. It also means that more growing space is reuired for small trees than called for by the idealized tand structure. Moreover, the higher the threshold iameter class, the greater is the proportion of the stand hat is unregulated. More growing space is occupied by rees of low value that will be cut as soon as they cross he threshold diameter (Alexander and Edminster 977b).

Marking Trees

After residual stocking goals have been calculated and a decision has been made on how to handle small trees, the stand must be marked. Marking is difficult in spruce-fir stands, because the marker must designate cut or leave trees, usually with one pass through the stand, based on limited inventory data. At the same time, the marker must apply good silviculture and be aware of

Table 8.—Actual stand conditions and management goals for stand B using basal area as the density measure[1]. All data on a per acre basis—stand goals; q = 1.5, residual basal area = 150 square feet, maximum tree diameter of 24 inches d.b.h. (Alexander and Edminster 1977b).

	Actual stand		Residual stand goal		Final stand		Cut	
Diameter class (inches) (1)	No. of trees (2)	Basal area (ft.^{2}) (3)	No. of trees (4)	Basal area (ft.^{2}) (5)	No., of trees (6)	Basal area (ft.^{2}) (7)	No., of trees (8)	Basal area (ft.^{2}) (9)
4	109	9.52	118.56	10.35	109	9.52	0	0
6	49	9.62	79.04	15.52	49	9.62	0	0
8	54	18.85	52.70	18.40	54	18.85	0	0
10	31	16.91	35.13	19.16	31	16.91	0	0
12	24	18.85	23.42	18.39	23	18.06	1	0.79
14	29	31.00	15.61	16.69	17	18.17	12	12.83
16	26	36.30	10.41	14.54	13	18.15	13	18.15
18	13	22.97	6.94	12.26	8	14.14	5	8.83
20	10	21.82	4.63	10.10	5	10.91	5	10.91
22	10	26.40	3.08	8.13	5	13.20	5	13.20
24	1	3.14	2.06	6.47	1	3.14	0	0
26	2	7.37	—	—	—	—	2	7.37
Total	358	222.75	351.58	150.01	315	150.67	43	72.18

[1] *Residual density parameter k for this example is computed as*

$$k = \frac{150.0}{0.57682 - 0.01454} = 266.77$$

[2] *Numbers of residual trees in each diameter class (col. 4) are computed by multiplying values in col. 6, table 4 by k.*

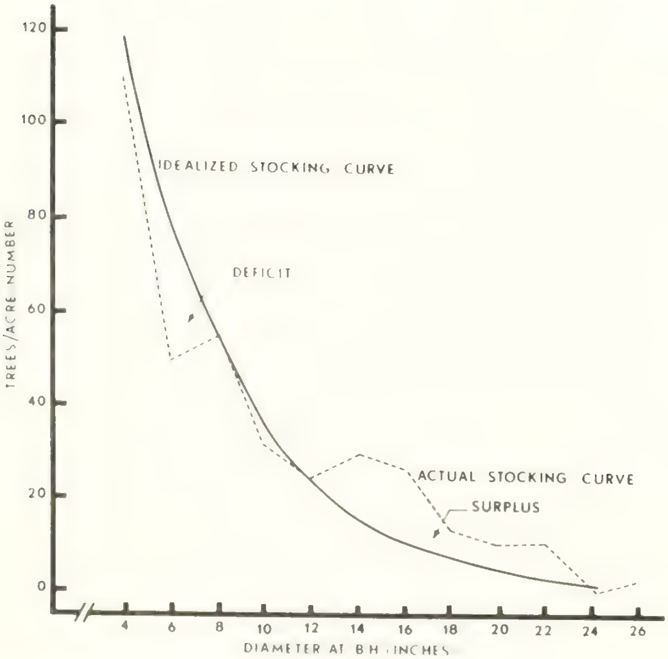


Figure 33.—Actual stocking curve of stand B from inventory data and the idealized stocking curve based on stand structure goals.

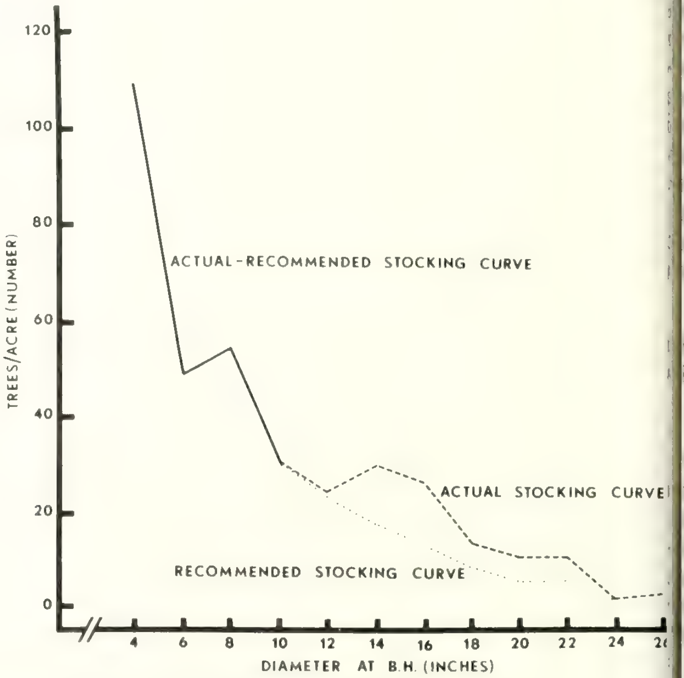


Figure 34.—Actual stocking curve of stand B and recommende stocking curve based on stand structure goals, actual stand struc ture, and management and silvicultural constraints.

onomic limitations. As a general rule, good silvi- ltural prescriptions are more important than strict herence to structural goals, especially in unregulated ands being cut for the first time. However, marking thout a structural goal—or prescribing structural goals at cannot be attained or applied—defeats the objective regulation.

Because marking for individual tree selection is more mplex than for other systems, some formal control pro- dure is necessary. Often, only an estimate of the initial id desired residual diameter distribution is needed. ith these estimates, basal areas and number of trees be removed per acre by diameter classes can be deter- ined. Control is maintained by a process of successive ecks of residual compared to the goal. For example, e markers should systematically make prism estimates the residual stand after marking, recording trees by or 4-inch classes on a standard cumulative tally sheet. riodically, they should convert the prism tally to trees r acre, and compare their average prism estimate to e structural goal. Markers must then adjust to any rious deviation from the structural goal, such as too avy marking in some diameter classes and too light others. Their next check will determine if progress being made or if further changes are needed. By this rocess, the average residual stand should come fairly ose to the structural goal (Alexander and Edminster 977b).

Recommendations for Selection Cutting

These are based on experience, windfall risk, and ruce beetle susceptibility. Selection cutting methods e appropriate for three- and multi-storied stands with regular or uneven-aged stand structure. Individual tree lection should be confined to stands with uniform acing. Group selection can be used in stands with ther clumpy-groupy spacing or uniform spacing. Selec- on cutting methods are not appropriate in high wind sk situations, or in stands sustaining a spruce beetle tack, or in stands where enough beetles are present ithin the stand or adjacent stands to make successful tacks.

tand Structure Goals, Cutting Treatments, and eentry Schedules

In low wind risk situations, not more than 30% to 40% f the stand basal area should be removed. With in- ividual tree selection, the cut should be distributed over e entire area. With group selection, not more than one- ird of area should be cut. If the stand is clumpy, the ze of opening should be determined by the size of the ump. If the stand is uniformly spaced, the size of open- g should not exceed two times tree height.

In above average wind risk situations, not more than 0% to 20% of the stand basal area should be removed. istribute the cut over the entire area with individual ee selection. Not more than one-fourth of the area hould be cut with group selection. Keep the openings small. If the stand is clumpy, the opening should be no larger than the size of the clump. If the stand is uniformly spaced, openings should not exceed 1 times tree height.

Maximum diameter should not exceed that attained in the unmanaged stand. The diameter distribution should be set at a q value that most closely approximates the natural q value of the stand. However, remember that low q values require cutting a larger number of trees at the threshold diameter class and high q values retain few larger trees. The threshold value should be set at the smallest diameter class practical. All trees below the threshold diameter class are unregulated. Some diameter classes will have a surplus of trees and some will have a deficit. Surpluses and deficits must be balanced if the residual basal area is to maintained. Subsequent entries should be made at 10- to 30-year intervals. While it would be desirable to enter the stand at 10-year intervals, it is not likely that this will be possible in most instances. Some diameter classes will not be completely represented; therefore, volumes available for cutting may not warrant a 10-year reentry until a controlled diameter distribution is attained.

Protecting the Residual Stand

Protection of the residual stand is critical with individual-tree selection cutting because of frequent entries into the stand once a controlled diameter distribution is attained. Damage can result from felling, skidding, and slash disposal.

Felling damage can be reduced by using group selection and dropping trees in the openings, or marking a small clump of trees where felling one large tree will damage several adjacent trees. Procedures outlined for protecting the residual for simulated shelterwood and disposing of slash for shelterwood cutting should be followed here.

COSTS OF SALE ADMINISTRATION AND LOGGING

Costs are important in harvesting spruce-fir stands, because the value of the timber has been moderate to low, and logging can be difficult because of terrain. One of the most important factors affecting the administrative cost of selling timber is the number of entries needed for harvesting. Clearcutting and simulated shelterwood require only one entry. Standard shelterwood requires two to three entries. Group shelterwood, and individual tree and group selection require from three to six entries, depending upon cutting cycles. In managed stands, even-aged systems could have additional entries for thinnings; but the number of entries under uneven-aged systems would not change (Alexander 1977).

Costs of sale layout, marking, and sale contract administration are lower for clearcutting, simulated and group shelterwood, group selection (when groups are near the maximum size), and the final cut of standard shelterwood than for individual tree selection, and the intermediate, preparatory and seed cuts of standard shelterwood. Costs are reduced, because only cutting boundaries are marked, and no time is spent marking each tree to cut or leave. Sale administration is easier, because there are no residual trees to protect and no opportunity to cut unmarked trees. However, reproduction must be protected at the time of final cut under any shelterwood system (Alexander 1977). Costs for selection methods are further increased, because highly skilled individuals are required to recognize, mark, and protect the trees needed to be left uncut in order to obtain and/or maintain the diameter distribution.

Timber harvesting usually requires road construction, because large acreages of spruce-fir forests are in unmanaged old-growth stands. Clearcutting is the most economical method in terms of volume removed per unit of road, while individual tree selection is the most expensive. Development of a transportation system to manage spruce-fir forests is a costly front-end investment that will require funding in addition to the value of stumpage at the time of first entry. Once the transportation system has been constructed, roads costs should be independent of cutting method (Alexander 1977).

In addition to producing maximum volume per acre in one operation, clearcutting permits the greatest flexibility in selection of logging equipment and minimum concern for protection of residual trees. The first entry of a standard shelterwood is intermediate in volume production per acre, requires moderate concern for the residual stand, and places some constraints on selection of equipment. The final cut of a standard shelterwood or simulated shelterwood has the advantages of clearcutting, except for the need to protect the new stand. Individual tree selection requires maximum concern for the residual stand. Group selection and group shelterwood require slightly less if the size of opening is near maximum. Under uneven-aged and group shelterwood cutting methods, volumes per entry are intermediate, size-class diversity of products harvested is maximum, and selection of logging equipment is restricted to smaller or specialized machines.

MULTIPLE-USE SILVICULTURE

SOIL AND WATER RESOURCES

Water Yield

In spruce-fir forests, where approximately 90% of natural streamflow (12 to 15 inches) comes from melting snow, water production is increased by cutting openings in the canopy (fig. 35). Size and arrangement of openings are critical. Largest increases in water available for streamflow (2.0+ inches) result when 30% to 40% of a drainage is harvested in small clearcut patches (3 to 5 acres) dispersed over the entire watershed (Leaf 1975; Leaf and Alexander 1975; Troendle 1982, 1983a, 1983b; Troendle and Leaf 1981). With this pattern, wind movement across the canopy is changed so that more snow accumulates in the openings than under adjacent stands.

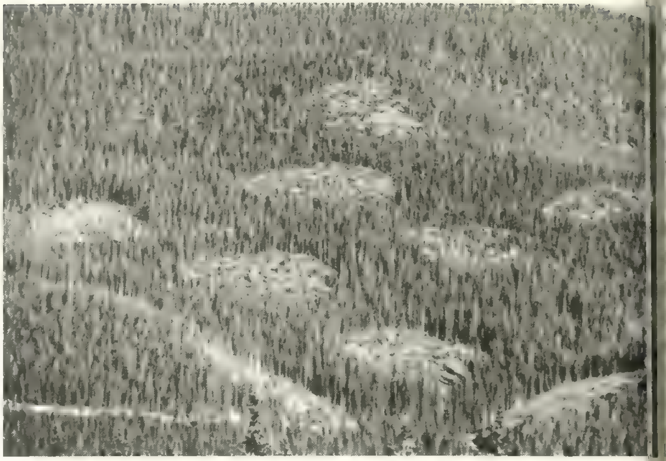


Figure 35.—Three-acre openings cut to increase streamflow, Fras
Experimental Forest.

Total snowfall in the drainage may or may not be i
creased by cutting, depending upon aspect (Hoover an
Leaf 1967, Troendle and Meiman 1984); but melt occu
earlier and at an increased rate in the openings, cau
ing the rising limb of the hydrograph to occur earli
than before timber harvest. Most of the increase in flo
occurs before the peak, which may be somewhat highe
but recession flows are about the same as before harves
Increase in streamflow is not likely to significant
diminish for 20 to 30 years, and treatment effect will n
disappear until the new stand in the openings is ta
enough to change the snow accumulation pattern.

At that time, a number of alternatives can be co
sidered. (1) Recut the original openings. The remainin
area would be retained as continuous high forest; tree
would be harvested periodically on an individual-tre
basis. Ultimately, the reserve stand would approach a
all-aged structure with the overstory canopy remainin
at about the same height, although the original overstor
could not be maintained indefinitely. (2) Make a light cu
distributed over the entire watershed, removing abou
20% to 30% of the basal area on an individual-tree bas
or in small groups. The objective would be to open u
the stand enough to develop windfirmness, and salvag
low-vigor and poor-risk trees. Openings five to eigh
times tree height can then be cut on about one-third
the area. The remaining two-thirds of the area would b
retained as permanent high forest, with trees periodicall
removed on an individual-tree basis or in small group
(3) Another alternative that would integrate water an
timber production would be to harvest all of the ol
growth in a cutting block in a series of cuts spread ove
120 to 160 years. Each cutting block would contain
least 300 acres, subdivided into circular or irregula
shaped units approximately 2 acres in size or four to fiv
times (in diameter) the height of the general canopy leve
At periodic intervals, some of these units, distribute
over the cutting block, would be harvested and the ope
ings would be regenerated. The interval between cutting
could vary from as often as every 10 years to as infr
quently as every 30 to 40 years. The percentage of uni
cut at each interval would be determined by cuttin
cycle/rotation age × 100. At the end of one rotation, eac

itting block would be composed of groups of trees in veral age classes ranging from reproduction to trees ady for harvest. The tallest trees would be somewhat iorter than the original overstory; but any adverse ef- ct on snow deposition should be minimized by keep- g the openings small and widely spaced (Alexander 974).

Cutting openings larger than 5 acres may be less effi- ent in increasing streamflow, because as opening size creases, wind can scour deposited snow causing it to aporate into the air or blow into adjacent stands where charge requirements and evapotranspiration are eater. However, these larger openings can be managed minimize wind scour and maintain snowpack on the te. By leaving residual stems standing and moderately eavy slash in place to provide roughness to hold snow, 0% to 30% more water can be retained in the snowpack ian in the uncut forest, even in relatively large openings.

Group selection and group shelterwood cutting can be early as favorable for water production as patch clear- utting, if openings are near the maximum size of 2 cres. Increase in water available for streamflow under dividual tree selection will be less than cutting small penings but still significantly higher than in the uncut rest. Canopy reduction by removing trees on an indi- dual basis results in less interception of snow and sub- equent evaporation from the canopy. This combined ith any other reduction in consumptive use (ET) can esult in greater streamflow (Troendle and Meiman 984).

Standard shelterwood results in increases similar to dividual tree selection as long as an overstory remains. fter final harvest under any standard shelterwood alter- ative, water available for streamflow may be expected increase to the level obtained under patch clearcut- ng, provided that the area cut is similar in size and rrangement to openings recommended for patch clear- utting. The interval of increased water yield will be pro- ortional to time required for the replacement stand to row tall enough to modify wind movement across the anopy (Alexander 1977).

Soil Erosion and Water Quality

Soil and site conditions are not the same in all spruce- r forests; but the careful location, construction, and aintenance of skid and haul roads associated with any lvicultural system should not cause a lasting increase sedimentation. For example, on the Fool Creek rainage in central Colorado, where about 12 miles of ain and secondary roads were constructed to remove mber in alternate clearcut strips from about one-third the drainage, annual sediment yields during road con- ruction and logging were only about 200 pounds per cre (Leaf 1970), and decreased rapidly after logging, espite a persistent increase in runoff. Annual sediment ields after logging have averaged about 43 pounds per cre, compared to 11 to 31 pounds from undisturbed atersheds (Leaf 1975).

Nutrient Losses and Stream Water Temperature Changes

Removal of logs in timber harvest represents a small and temporary net loss of nutrients, because only a minor proportion of the nutrients taken up by a tree is stored in the bole. Clearcutting spruce-fir forests results in a greater immediate loss than individual tree selection; but over a rotation, the losses would balance out because of more frequent cuts under the selection system. Furthermore, nutrients lost after clear cutting should be replaced in 10 to 20 years through natural cycling as regeneration becomes established (Alexander 1977).

Comparison of streamflow from logged and unlogged subalpine watersheds in central Colorado provided some indication of effect on chemical water quality. Ten years after clearcutting, cation concentration during a 10-week period was 1.8 ppm greater and cation outflow 5.2 pounds per acre per year greater on the logged watershed (Stottlemyer and Ralston 1968).

Increases in stream temperature can be avoided, even with clearcutting, by retaining a border of trees along stream channels. Actually, clearcutting to the stream channel and subsequent warming of the water may be advantageous in spruce-fir forests, where streams are frequently small and too cold to support adequate food supplies for fish (Alexander 1977).

WILDLIFE AND RANGE RESOURCES

Game Habitat

Spruce-fir forests provide summer habitat for mule deer and elk, and yearlong habitat for blue grouse (*Dendragapus obscurus* Say). Clearcutting, group shelterwood, and group selection provide the largest increases in quantity and quality of forage for big game; but use often is limited by the amount of cover available for hiding, resting, and ruminating. Furthermore, game populations are not directly related to forage availability on summer ranges, because carrying capacity of winter ranges limits the number of animals. Mature unlogged spruce-fir stands in Colorado produce enough forage to support more mule deer than are presently estimated to occupy summer ranges (Regelin et al. 1974).

Dispersed openings 2 to 20 acres in size are used more by deer and elk than smaller or larger openings or uncut timber (Regelin and Wallmo 1978, Reynolds 1966, Wallmo 1969, Wallmo et al. 1972). Small openings provide little diversity, and overly large openings radically alter habitat, especially if they are coupled with extensive site preparation and tree planting. As trees grow to seedling and sapling size, forage production in cleared areas diminishes, but cover increases. Forage increases again as stands reach sawlog size and cover approaches the maximum for the spruce-fir type.

Openings created by harvesting are preferred to natural openings, because the vegetation that initially comes in on cutover areas is more palatable to deer and elk. Reynolds (1966) suggested that openings be maintained by cleaning up the logging slash and debris, removing new tree reproduction, and seeding the area to forage species palatable to big-game. However, because natural succession on areas is likely to replace the more palatable species in 15 to 20 years (Regelin and Wallmo 1978), a more desirable alternative would be to cut new openings periodically while allowing the older cuttings to regenerate. That would provide a constant source of palatable forage and the edge effect desired. The openings created should be widely spaced, with stands between openings maintained as high forest (Alexander 1977).

One alternative that would integrate wildlife habitat improvement with timber production would be to cut about one-sixth of a cutting block every 20 years in openings about four to five times tree height. Each working circle would be subdivided into a number of cutting blocks (of at least 300 acres), so that not all periodic cuts would be made in a single year on a working circle. Such periodic cutting would provide a good combination of numbers and species of palatable forage plants and the edge effect desired, while creating a several-aged forest of even-aged groups (Alexander 1974).

Standard shelterwood cutting provides less forage for big game than cutting methods that create openings; and the reduction is in proportion to the density of the overstory and length of time it is retained. Shelterwood cutting also provides less cover than an uncut forest. Individual tree selection provides forage and cover comparable to uncut forests, thus maintaining one type of habitat at the expense of creating diversity (Alexander 1977).

Game animals other than deer or elk also are influenced by the way forests are managed. For example, with the decrease in wildfires, some reduction in stand density by logging may be necessary to create or maintain drumming grounds for male blue grouse. Standard shelterwood, group shelterwood, or group selection cutting that opens up the stand enough to allow regeneration to establish in thickets provides desirable cover. Small, dispersed clearcuts (5 to 10 acres) also are favorable if thickets of new reproduction become established (Martinka 1972).

Nongame Habitat

Little information is available on the relationship of cutting methods in spruce-fir forests to specific nongame habitat requirements; but it is possible to estimate probable effects. Clearcutting, group shelterwood, and group selection that create small, dispersed openings provide a wide range of habitats attractive to some birds and small mammals by increasing the amount of nontree vegetation—at least initially—and length of edge between dissimilar vegetation types. On the Fool Creek watershed, for example, where 40% of the timber was cleared in alternate strips one to six chains wide, many species of birds feed in openings and nest in trees along the edge. In contrast, only woodpeckers and sapsuckers have been observed in adjacent uncut stands (Myers and Morris
1975). However, Scott et al. (1982) compared numbe
and species of nongame birds on two 100-acre su
drainages on Deadhorse Creek, in the Fraser Experime
tal Forest. One-third of one subdrainage was clearcut
3-acre patches; the other was left uncut. They found th
total numbers of birds did not significantly change wi
cutting. However, there was a small postharvest decli
in the "foliage nesting" and "picker" and "gleane
feeding guilds. There were no significant changes
small mammal populations after timber harvest.

In the central Rocky Mountains, spruce-fir forests co
monly occur on habitat types that can support lodgepo
pine and aspen. Where these species are components
existing spruce-fir stands, clearcutting can increase the
representation in the replacement stand, thereby creati
a diversity in cover types. This increase in diversity
generally desirable for a variety of nongame wildlif

Standard shelterwood cutting provides a variety
habitats attractive to species that forage in stands wi
widely spaced trees, but not to those that require clos
forests or fully open plant communities. Under th
method, trees are still available for nesting, denning, a
feeding until the final harvest, when considerati
should be given to retaining some of the snags and li
trees with cavities (Alexander 1977). To insure futu
cavities, Scott et al. (1978) recommended leaving
broken-top snags greater than 8 inches d.b.h. and li
trees with broken-tops or scars.

Harvesting old-growth timber can be devasting
species that nest or den in snags and in cavities of li
trees, feed largely on tree seeds, or require solita
habitats with continuous forest cover. Individual tr
selection provides the least horizontal diversity, a
favors species attracted to uncut forests or that requi
vertical diversity. However, snags and live tree caviti
can be retained under any silvicultural system (Ale
ander 1977).

Livestock Grazing

Much grazing land is adjacent to or intermingled wi
spruce-fir forests. While the quantity and quality
forage produced varies with habitat type, forage produ
tion under a mature canopy is usually light and gener
ly not readily accessible to livestock. The quantity a
quality of forage increases in proportion to the amou
of canopy removed. Utilization of available forage usu
ly is greater in large clearcut areas, because forage
more accessible to livestock. Forage production in ope
ings decreases rapidly as new trees grow out of t
seedling-sapling stage; and it can be maintained only
frequent cuttings (Alexander 1977).

RECREATION AND ESTHETICS

Spruce-fir forests provide a variety of recreation o
portunities. Users who hike, backpack, ski, tour, or vie
scenery are generally attracted to forests whose natur
appearance is little altered by human activities (Calv

72). In contrast, hunters have best success where man activities are apparent—timber sales and other eas readily accessible by roads. Fishing is mostly done accessible lakes, reservoirs, and streams. Generally, ost camping opportunities are at both publicly and rivately developed sites served by roads. Most scenery ewing is by automobile on developed roads. Moreover, ost of the winter use of snowmobiles for recreation in ruce-fir forests is on roads. Finally, some forms of creation, such as downhill skiing and mountain home evelopment, require drastic modification of the natural rest landscape (Alexander 1977).

Clearcutting has the greatest visual impact, and inividual tree selection has the least. However, variety pical of forests at the highest elevations—whose texure is broken by natural openings—is preferred to the onotony of vast, unbroken forest landscapes at midle and lower elevations (Kaplan 1973). In addition, spen, a seral species, which is a major esthetic resource, an be maintained by clearcutting.

To enhance amenity values, openings cut for timber nd water production and wildlife habitat improvement hould be a repetition of natural shapes, visually tied gether to create a balanced and unified pattern that will omplement the landscape (Barnes 1971). This is espeially important for openings in the middleground and ackground seen from a distance. Standard or simulated helterwood, or individual tree selection can be used to etain a landscape in foregrounds. Well planned clearut openings also can be used to create and maintain istas along major road systems.

Individual tree selection, group selection, and group helterwood cutting are appropriate in high-use recreaon areas, travel influence zones, scenic-view areas, and nds adjacent to ski runs—and also near support facilies and subdivision developments where permanent orest cover is desired. The visual impact of logging can e minimized by cleanup of debris and slash and by areful location of roads (Alexander 1977).

OMPARISON OF CUTTING METHODS

A comparison of the effects of different silvicultural ystems, and cutting methods, and their modifications, n resource values and timber economics in spruce-fir orests is shown in figure 36. These relative rankings are ased on research and experience, and are subject to hange as additional information on resource interacons becomes available.

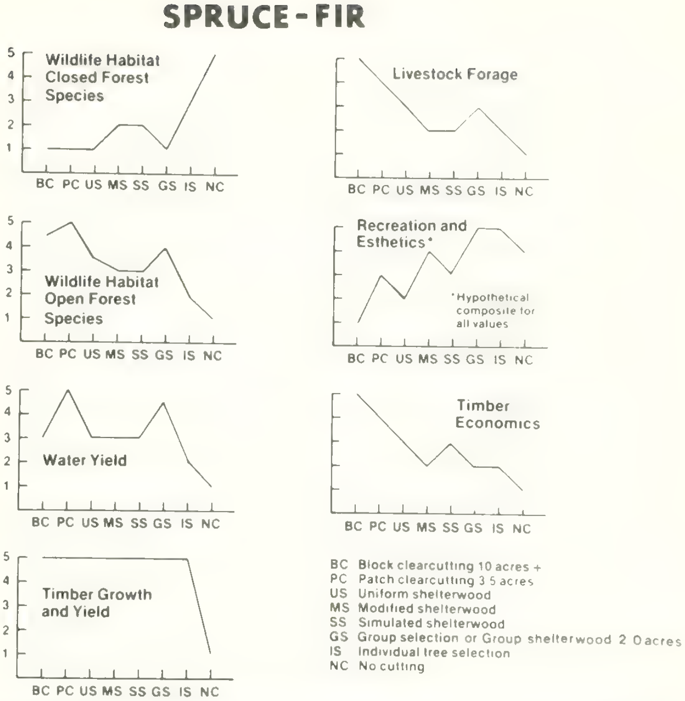


Figure 36.—Relative ranking of the effects of cutting methods on the resources of spruce-fir forests. Scale: 1 = least favorable, 5 = most favorable.

No silvicultural system or cutting method (including o cutting at all) meets all resource needs. Cutting small penings provides maximum yields of timber at mininum costs, promotes the largest increases in water prouction without serious reduction in quality, produces iversity in food supply and cover favored by many ildlife species, and is necessary for the development f recreation sites for skiing and home subdivisions. Prouction and utilization of livestock forage are less than n larger openings, while clearcutting in any form detroys the habitat of wildlife species that dwell in closed forests. Clearcutting can create adverse visual effects if no thought is given to the size and arrangement of the openings; but it can also be used to create landscape variety that will enhance amenity values.

Standard and simulated shelterwood cutting also provide maximum timber yields over the same time interval, but at increased costs; they produce a wide range of wildlife habitats, but with less forage than openings and less cover than uncut forests. Water yields are increased significantly over natural streamflow, but not as much as clearcutting small openings. Shelterwood cutting provides a partial retention of the forest landscape, particularly when the overstory is retained for a long time (Alexander 1977).

Group selection and group shelterwood cutting, with the size of opening near the maximum, favor and discriminate against the same resource values as patch or strip clearcutting. They are more expensive and less flexible, however. Individual tree selection cutting can maintain high levels of timber production; but it is the most expensive harvesting method. Water yields are greater than in uncut forests. Individual tree selection cutting provides minimum horizontal diversity in wildlife habitat, but favors species attracted to uncut forests. It also provides good partial retention of the natural forest landscape. Group selection with very small openings accomplishes about the same things as individual tree selection (Alexander 1977).

Not all resource needs can be met on a given site, nor is any one cutting method compatible with all uses. Land managers must recognize the potential multiple-use values of each area, determine the primary and secondary uses, and then select the management alternative that is most likely to enhance or protect these values. On an individual site, some uses probably must be sacrificed or diminished to maintain the quantity and quality of others (Alexander 1977).

Within a given area, a variety of cutting methods usually should be prescribed to meet diverse management objectives. However, cutting methods should take advantage of existing stand conditions and access, and account for damaging agents, as well as management objectives.

LITERATURE CITED

Alexander, Robert R. 1956. A comparison of growth and mortality following cutting in old-growth mountain spruce-fir stands. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Research Note 20, 4 p. Fort Collins, Colo.

Alexander, Robert R. 1957. Damage to advanced reproduction in clearcutting spruce-fir. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Research Note 27, 3 p. Fort Collins, Colo.

Alexander, Robert R. 1963. Harvest cutting old-growth mountain spruce-fir in Colorado. Journal of Forestry 61:115-119.

Alexander, Robert R. 1964. Minimizing windfall around clear cuttings in spruce-fir forests. Forest Science 10:130-142.

Alexander, Robert R. 1966. Stocking of reproduction on spruce-fir clearcuttings in Colorado. USDA Forest Service Research Note RM-72, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1967. Windfall after clearcutting on Fool Creek—Fraser Experimental Forest, Colorado. USDA Forest Service Research Note RM-92, 11 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1968. Natural reproduction of spruce-fir after clearcutting in strips, Fraser Experimental Forest. USDA Forest Service Research Note RM-101, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1969. Seedfall and establishment of Engelmann spruce in clearcut openings: A case history. USDA Forest Service Research Paper RM-53, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1973. Partial cutting in old-growth spruce-fir. USDA Forest Service Research Paper RM-110, 16 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA Forest Service Research Paper RM-121, 88 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1977. Cutting methods in relation to resource use in central Rocky Mountain spruce-fir forests. Journal of Forestry 75:395-400.

Alexander, Robert R. 1980. Engelmann spruce-subalpi fir 206. p. 86-87. *In* F. A. Eyre, editor. Forest cov types of the United States and Canada. Society American Foresters, Washington, D.C.

Alexander, Robert R. 1983. Seed: seedling ratios of Eng mann spruce after clearcutting in the central Roc Mountains. USDA Forest Service Research N RM-426, 6 p. Rocky Mountain Forest and Range E periment Station, Fort Collins, Colo.

Alexander, Robert R. 1984. Natural regeneration Engelmann spruce after clearcutting in the cent Rocky Mountains in relation to environmental facto USDA Forest Service Research Paper RM-254, 17 Rocky Mountain Forest and Range Experiment St tion, Fort Collins, Colo.

Alexander, Robert R. 1985a. Diameter and basal ar distributions in old-growth spruce-fir stands on t Fraser Experimental Forest. USDA Forest Servi Research Note RM-451, 4 p. Rocky Mountain Fore and Range Experiment Station, Fort Collins, Colo

Alexander, Robert R. 1985b. Major habitat types, co munity types, and plant communities in the Roc Mountains. USDA Forest Service General Technic Report RM-123, 105 p. Rocky Mountain Forest a Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1977 Regulation and control of cut under uneven-ag management. USDA Forest Service Research Pap RM-182, 7 p. Rocky Mountain Forest and Range E periment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1977 Uneven-aged management of old-growth spruce- forests: Cutting methods and stand structure goals f initial entry. USDA Forest Service Research Pap RM-186, 12 p. Rocky Mountain Forest and Range E periment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 198 Management of spruce-fir in even-aged stands in t central Rocky Mountains. USDA Forest Servi Research Paper RM-217, 14 p. Rocky Mountain Fore and Range Experiment Station, Fort Collins, Colo

Alexander, Robert R., and Carleton B. Edminster. 198 Engelmann spruce seed dispersal in the central Roc Mountains. USDA Forest Service Research No RM-424, 4 p. Rocky Mountain Forest and Range E periment Station, Fort Collins, Colo.

Alexander, Robert R., and Orville Engelby. 1983. Eng mann spruce—subalpine fir. p. 59-64. *In* R. E. Burn technical compiler. Silvicultural systems for maj forest types of the United States. U.S. Department Agriculture, Forest Service, Agricultural Handbo 445, 191 p. Washington, D.C.

Alexander, Robert R., Raymond C. Shearer, and Way D. Shepperd. 1984. Silvical characteristics of subalpi fir. USDA Forest Service General Techical Repo RM-115, 29 p. Rocky Mountain Forest and Range E periment Station, Fort Collins, Colo.

Alexander, Robert R., and Wayne D. Shepperd. 198 Silvical characteristics of Engelmann spruce. USD Forest Service General Technical Report RM-114, 38 Rocky Mountain Forest and Range Experiment St tion, Fort Collins, Colo.

exander, Robert R., Ross K. Watkins, and Carleton B. Edminster. 1982. Engelmann spruce seed production on the Fraser Experimental Forest, Colorado. USDA Forest Service Research Note RM-419, 6 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

ker, Frederick S. 1949. A revised tolerance table. Journal of Forestry 47:179-181.

rnes, R. Lawrence. 1971. Patterned tree harvest proposed. Western Conservation Journal 28:44-47.

nd, E. W. 1952. Growing stock differences in even-aged and all-aged forests. Journal of Forestry 50:691-693.

urne, R. 1951. A fallacy in the theory of growing stock. Forestry 24:6-18.

ffam, P. E., C. K. Lister, R. E. Stevens, and R. H. Frye. 1973. Fall cacodylic acid treatments to produce lethal traps for spruce beetles. Environmental Entomology 2:259-262.

lvin, J. S. 1972. An attempt at assessing preferences for natural landscapes. Environment and Behavior 4(4):447-470.

rniss, R. L., and V. M. Carolin. 1977. Western forest insects. U.S. Department of Agriculture, Forest Service, Miscellaneous Publication No. 1339, 654 p. Washington, D.C.

een, Allen W., and Duane D. Van Hooser. 1983. Forest resources of the Rocky Mountain states. USDA Forest Service Research Bulletin INT-33, 127 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

anley, David P., Wyman C. Schmidt, and George M. Blake. 1975. Stand succession and successional status of two spruce-fir forests in southern Utah. USDA Forest Service Research Paper INT-176, 16 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

awksworth Frank G., and Delbert Wiens. 1972. Biology and classification of dwarf mistletoes (*Arceuthobium*). U.S. Department of Agriculture, Forest Service, Agricultural Handbook No. 410, 204 p. Washington, D.C.

nds, T. E. 1977. Heart rots of Engelmann spruce and subalpine fir in the central Rocky Mountains. U.S. Department of Agriculture, Forest Service, Forest Insect and Disease Leaflet 150, 8 p. Rocky Mountain Forest and Range Experiment Station, Washington, D.C.

nds, Thomas E., and Frank G. Hawksworth. 1966. Indicators and associated decay of Engelmann spruce in Colorado. USDA Forest Service Research Paper RM-25, 15 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

nds, Thomas E., Frank G. Hawksworth, and Ross W. Davidson. 1960. Decay of subalpine fir in Colorado. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Station Paper 51, 13 p. Fort Collins, Colo.

odson, E. R., and J. H. Foster. 1910. Engelmann spruce in the Rocky Mountains. U.S. Department of Agriculture, Forest Service, Circular 170, 23 p. Washington, D.C.

Hoover, Marvin D., and Charles F. Leaf. 1965. Process and significance of interception in Colorado subalpine forest. p. 213-224. *In* W. E. Sopper and H. W. Lull, editors. Forest Hydrology: International Symposium on Forest Hydrology [University Park, Penn., Aug.-Sept. 1965]. Pergamon Press, New York, N.Y.

Hopkins, A. D. 1909. Practical information on the scolytid beetles in North American forests. I. Barkbeetles of the genus *Dendroctonus*. U.S. Department of Agriculture, Entomology Bulletin 83, pt. 1, 169 p. Washington, D.C.

Hornibrook, E. M. 1950. Estimating defect in mature and over mature stands of three Rocky Mountain conifers. Journal of Forestry 48:408-417.

Kaplan, R. 1973. Predictors of environmental preferences. Designers and "clients." p. 265-274. *In* W. F. E. Prieser, editor. Environmental Design Research. Proceedings of fourth international EDRA conference. [Blacksburg, Va, April 1973]. Dowden, Hutchinson, and Ross, Stroudsburg, Penn.

Keen, F. P. 1952. Insect enemies of western forests. U.S. Department of Agriculture, Miscellaneous Publication 273, 280 p. Washington, D.C.

Knight, F. B., W. F. McCambridge, and B. H. Wilford. 1956. Estimating Engelmann spruce beetle infestations in the central Rocky Mountains. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Station Paper 25, 12 p. Fort Collins, Colo.

Leaf, C. F. 1970. Sediment yields from central Colorado snow zone. American Society of Civil Engineering, Journal of Hydraulic Division 96(HY1):87-93, 97(HY2): 350-351.

Leaf, Charles F. 1975. Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge. USDA Forest Service Research Paper RM-137, 31 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Leaf, Charles F., and Robert R. Alexander. 1975. Simulating timber yields and hydrologic impacts resulting from timber harvest on subalpine watersheds. USDA Forest Service Research Paper RM-133, 20 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

LeBarron, Russell K., and George M. Jemison. 1953. Ecology and silviculture of the Engelmann spruce-subalpine fir type. Journal of Forestry 51:349-355.

Martinka, Robert R. 1972. Structural characteristics of blue grouse territories in southwestern Montana. Journal of Wildlife Management 36:489-510.

Massey, C. L., and N. D. Wygant. 1954. Biology and control of the Engelmann spruce beetle in Colorado. U.S. Department of Agriculture, Circular 944, 35 p. Washington, D.C.

Mathiasen, R. L., and F. G. Hawksworth. 1983. Dwarf mistletoes on true firs in the Southwest. Northern Arizona University, School of Forestry, Arizona Forestry Notes No. 18, 12 p. Flagstaff, Ariz.

McCaughey, Ward W., and Wyman C. Schmidt. 1982. Understory tree release following harvest cutting in spruce-fir forests of the Intermountain West. USDA Forest Service Research Paper INT-285, 19 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Meyer, H. A. 1952. Structure, growth and drain in balanced uneven-aged forests. Journal of Forestry 50:85-92.

Meyer, H. A., A. D. Recknagel, D. D. Stevenson, and R. A. Bartoo. 1961. Forest Management. 282 p. The Roland Press Company, New York, N.Y.

Miller, Phillip C. 1970. Age distributions of spruce and fir in beetle-killed stands on the White River Plateau. American Midland Naturalist 83:206-212.

Myers, C. A., and M. J. Morris. 1975. Watershed management practices and habitat values in coniferous forests. p. 288-294. *In* Proceedings, Symposium on management of forest and range habitats for nongame birds. [Tucson, Ariz., May 6-9, 1975]. USDA Forest Service General Technical Report WO-1, 6 p. Washington, D.C.

Nagel, R. H., David McComb, and F. B. Knight. 1957. Trap tree method for controlling the Engelmann spruce beetle in Colorado. Journal of Forestry 55:894-898.

Noble, Daniel L., and Frank Ronco. 1978. Seedfall and the establishment of Engelmann spruce and subalpine fir in clearcut openings in Colorado. USDA Forest Service Research Paper RM-200, 12 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Oosting, Henry J., and John F. Reed. 1952. Virgin spruce-fir in the Medicine Bow Mountains, Wyoming. Ecology Monograph 22:69-91.

Peterson, Roger S. 1963. Effects of broom rusts on spruce and fir. USDA Forest Service Research Paper INT-7, 10 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Regelin, Wayne L., Olof C. Wallmo, Julius G. Nagy, and Donald R. Dietz. 1974. Effect of logging on forage values for deer in Colorado. Journal of Forestry 72:282-285.

Regelin, Wayne L., and Olof C. Wallmo. 1978. Duration of deer forage benefits after clearcut logging of subalpine forest in Colorado. USDA Forest Service Research Note RM-356, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Retzer, John L. 1956. Alpine soils of the Rocky Mountains. Journal of Soil Science 7:22-32.

Reynolds, Hudson G. 1966. Use of openings in spruce fir forests by deer, elk and cattle. USDA Forest Service Research Note RM-63, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Reynolds, R. R. 1954. Growing stock in all-aged forests. Journal of Forestry 52:744-747.

Roe, Arthur L. 1967. Seed dispersal in a bumper spruce seed year. USDA Forest Service Research Paper INT-39, 10 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Roe, Arthur L., Robert R. Alexander, and Milton D Andrews. 1970. Engelmann spruce regeneration practices in the Rocky Mountains. USDA Forest Service Production Research Report 115, 32 p. Washington, D.

Roe, Arthur L., and G. M. DeJarnette. 1965. Results o regeneration cutting in a spruce-subalpine fir stand USDA Forest Service Research Paper INT-17, 4 p. Intermountain Forest and Range Experiment Station Ogden, Utah.

Ronco, Frank. 1970. Shading and other factors affec survival of planted Engelmann spruce seedlings in central Rocky Mountains. USDA Forest Service Researc Note RM-163, 7 p. Rocky Mountain Forest and Rang Experiment Station, Fort Collins, Colo.

Schmid, John M. 1977. Guidelines for minimizing spruc beetle populations in logging residuals. USDA Fores Service Research Paper RM-185, 8 p. Rocky Mountai Forest and Range Experiment Station, Fort Collins Colo.

Schmid, John M., and Roy C. Beckwith. 1971. The Engelmann spruce beetle. U.S. Department of Agriculture Forest Service, Forest Pest Leaflet 127, 7 p. Washington, D.C.

Schmid, J. M., and R. H. Frye. 1977. Spruce beetle i the Rockies. USDA Forest Service General Technica Report RM-49, 38 p. Rocky Mountain Forest an Range Experiment Station, Fort Collins, Colo.

Schmid, J. M., and T. E. Hinds. 1974. Development o spruce-fir stands following spruce beetle outbreaks USDA Forest Service Research Paper RM-131, 16 p Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Scott, Virgil E., Glenn L. Crouch, and Jill A. Whelan 1982. Responses of birds and small mammals to clear cutting in a subalpine forest in central Colorado. USD Forest Service Research Note RM-422, 6 p. Rock Mountain Forest and Range Experiment Station, For Collins, Colo.

Scott, Virgil E., Jill A. Whelan, and Robert R. Alexande 1978. Dead trees used by cavity-nesting birds on th Fraser Experimental Forest: A case history. USD Forest Service Research Note RM-360, 4 p. Rock Mountain Forest and Range Experiment Station, For Collins, Colo.

Society of American Foresters. 1980. Forest cover type of the United States and Canada. 148 p. F. H. Eyre editor. Washington, D.C.

Stahelin, R. 1943. Factors influencing the natural restocking of high altitude burns by coniferous trees in th central Rocky Mountains. Ecology 24:19-30.

Stevens, Robert E. 1971. Fir-engraver. U.S. Departmen of Agriculture, Forest Pest Leaflet 13, 7 p. Washington D.C.

Stottlemeyer, J. R., and C. W. Ralston. 1968. Nutrien balance relationships for watersheds on the Fraser Experimental Forest. p. 3:359-382. *In* Proceedings Nort American forest soils conference. [Raleigh, N.C., 1968 North Carolina State University.

Sudworth, George B. 1900a. White River Plateau timbe land reserve. p. 117-179. *In* Twentieth annual repor 1898-1899. Part V Forest Reserves. U.S. Geologica Survey, Washington, D.C.

lworth, George B. 1900b. Battlement Mesa forest re- erve. p. 181-243. *In* Twentieth annual report, 898-1899. Part V Forest Reserves. U.S. Geological urvey, Washington, D.C.

endle, Charles A. 1982. The effects of small clearcuts n water yield from the Deadhorse watershed; Fraser, olorado. p. 75-83. *In* Proceedings, 50th annual meet- g of the Western Snow Conference. [Reno, Nev., pril 19-23, 1982]. Colorado State University, Fort Col- ns, Colo.

endle, Charles A. 1983a. The Deadhorse experiment: field verification of the subalpine water balance nodel. USDA Forest Service Research Note RM-425, p. Rocky Mountain Forest and Range Experiment tation, Fort Collins, Colo.

endle, C. A. 1983b. The potential for water yield aug- nentation from forest management in the Rocky Mountain Region. American Water Resources Associa- ion, Water Resources Bulletin 19:359-373.

endle, Charles A., and Charles F. Leaf. 1981. Effects f timber harvesting in the snow zone on volume and iming of water yield. p. 231-243. *In* David A. Baum- artner, editor and compiler. Proceedings, Interior West Watershed Symposium. [Spokane, Wash., April -10, 1980]. Cooperative Extension, Washington State University, Pullman, Wash.

endle, Charles A, and James E. Meiman. 1984. Op- ions for harvesting timber to control snowpack accumulation. p. 86-98. *In* Proceedings, 52nd Annual Meeting of the Western Snow Conference. [Sun Valley, daho, April 17-19, 1984]. Colorado State University, Fort Collins, Colo.

U.S. Department of Agriculture, Forest Service. 1933. Annual report (twenty-third year). (1932) Mimeograph Rocky Mountain Region. Rocky Mountain Forest and Range Experiment Station, Washington, D.C.

U.S. Department of Agriculture, Forest Service. 1983. Silvicultural systems for the major forest types of the United States. R. E. Burns, technical compiler. Agricultural Handbook No. 445. Washington, D.C.

Wallmo, O. C. 1969. Response of deer to alternate-strip clearcutting of lodgepole pine and spruce-fir timber in Colorado. USDA Forest Service Research Note RM-141, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Wallmo, O. C., W. L. Regelin, and D. W. Reichert. 1972. Forage use by mule deer relative to logging in Colorado. Journal of Wildlife Management 36:1025-1033.

Whipple, Stephen A., and Ralph L. Dix. 1979. Age structure and successional dynamics of a Colorado subalpine forest. American Midland Naturalist 101: 142-158.

Whiteside, J. M., and V. M. Carolin, Jr. 1961. Spruce budworm in the western United States. U.S. Department of Agriculture, Forest Service, Forest Pest Leaflet 53, 8 p. Washington, D.C.

Wygant, N. D. 1958. Engelmann spruce beetle control in Colorado. *In* Proceedings, 10th International Congress of Entomology, No. 4:181-184.

Wygant, N. D., and R. R. LeJeune. 1967. Engelmann spruce beetle *Dendroctonus obesus* (Mann) (=*D. engelmannii* Hopk.). p. 93-95. *In* Important forest insects and diseases of mutual concern to Canada, the United States and Mexico. Publication 1180. Canadian Department of Forest and Rural Development, Ottawa, Ont.

Alexander, Robert R. 1986. Silvicultural systems and cutting methods for old-growth spruce-fir forests in the central and southern Rocky Mountains. USDA Forest Service General Technical Report RM-126, 33 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Guidelines are provided to help the forest manager and silviculturist develop even- and/or uneven-aged cutting practices needed to convert old-growth spruce-fir forests into managed stands for a variety of resource needs. Guidelines consider stand conditions, succession, windfall risk, and insect and disease susceptibility. Cutting practices are designed to integrate timber production with increased water yield, maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing.

Keywords: Silvicultural systems, timber harvesting, forest resources, *Picea engelmannii, Abies lasiocarpa*

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Silvicultural Systems and Cutting Methods for Old-Growth Lodgepole Pine Forests in the Central Rocky Mountains

Robert R. Alexander

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Abstract

Guidelines are provided to help forest managers and silviculturists develop even- and uneven-aged cutting practices needed to convert pure and mixed old-growth lodgepole pine forests into managed stands. Guidelines consider stand conditions, succession, windfall risk, and insect and disease susceptibility. Cutting practices—clearcutting, shelterwood, and selection—are designed to integrate timber production with increased water yield, maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic beauty.

Cover Photo.—Old-growth lodgepole pine on the Fraser Experimental Forest, Colorado.

SDA Forest Service
neral Technical Report RM-127

April 1986

Silvicultural Systems and Cutting Methods for Old-Growth Lodgepole Pine Forests in the Central Rocky Mountains

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Rocky Mountain Forest and Range Experiment Station[1]

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[1] *Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Contents

Page

NATURAL STANDS 1
  AGE-CLASS DISTRIBUTION 1
  REACTION TO COMPETITION 1
  STAND CONDITIONS 2
DAMAGING AGENTS 2
  WIND 2
  INSECTS 3
    Bark Beetles 3
    Other Insects 3
  DISEASES 4
    Dwarf Mistletoe 4
    Rust Fungi 4
    Other Diseases 5
  FIRE 5
  ANIMALS 5
CUTTING HISTORY 5
REGENERATION SILVICULTURAL SYSTEMS 7
  EVEN-AGED CUTTING METHODS 7
    Management with Advanced Regeneration 7
      Simulated Shelterwood Cutting 7
    Management for Natural Regeneration After Cutting 8
      Clearcutting 8
      Shelterwood Cutting 11
  UNEVEN-AGED CUTTING METHODS 18
    Individual Tree Selection Cutting 18
    Group Selection Cutting 19
    Stand Structure Goals 19
      Control of Stocking 19
      Maximum Tree Size 19
      Control of Diameter Distribution 19
    How to Determine Residual Stand Structure 20
    How to Handle Small Trees 22
    Marking Trees 23
    Recommendations for Selection Cutting 23
  Stand Structure Goals, Cutting Treatments, and Reentry Schedules 23
    Protecting the Residual Stand 24
COSTS OF SALE ADMINISTRATION AND LOGGING 24
MULTIPLE-USE SILVICULTURE 24
  POTENTIAL TIMBER YIELDS 24
  SOIL WATER RESOURCES 24
    Water Yield 24
    Soil Erosion and Water Quality 25
    Nutrient Losses and Stream Water Temperature Changes 25
  WILDLIFE AND RANGE RESOURCES 26
    Game Habitat 26
    Nongame Habitat 26
    Livestock Grazing 27
  RECREATION AND ESTHETICS 27
  COMPARISON OF CUTTING METHODS 27
LITERATURE CITED 28

Silvicultural Systems and Cutting Methods for Old-Growth Lodgepole Pine Forests in the Central Rocky Mountains

Robert R. Alexander

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) forests SAF Type 218) (Pfister and McDonald 1980) are second n multiple-use importance only to Engelmann spruce Picea engelmannii Parry ex Engelm.)—subalpine fir Abies lasiocarpa (Hook.) Nutt.) forests in the central Rocky Mountains. These forests occupy about 3.2 million acres of timberland, with an estimated 18 billion board feet (INT 1/4 Rule) of sawtimber in Colorado and Wyoming (Green and Van Hooser 1983). They grow on areas where timber production potential varies from high to very low. These forests also provide watershed protection, streamflow, habitat for wildlife, forage for livestock, recreational opportunities, and scenic beauty. Many areas now occupied by lodgepole pine have the potential for growing Engelmann spruce and subalpine fir or Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* Beissn.) Franco) (Alexander 1974, Alexander et al. 1983).

NATURAL STANDS

AGE-CLASS DISTRIBUTION

About one-half (47%) of the stocked natural lodgepole pine area is in sawtimber stands. Much of these stands are overmature and declining in general vigor and soundness (Alexander 1974, Green and Van Hooser 1983).

Thirty-eight percent of the lodgepole pine is in poletimber stands; but much of the poletimber is either overmature, overly dense, or growing on sites not likely to produce a sawlog-sized tree. Most of these stands became established after wildfires burned between the late 1800s and the early 1900s. Because wildfires are random events, poletimber stands are abundant in some areas and rare in others. About 12% of the lodgepole pine forests in the central Rocky Mountains are classified as seedling and sapling stands that originated after either fire or timber harvest. Many of these stands are overly dense and require thinning to reduce stocking. Only about 3% of the lodgepole pine timberland is classified as nonstocked. Failure of tree reproduction after clearcutting large areas where the nonserotinous cone habit s prevalent accounts for some of the nonstocked area; but not all nonstocked lands now classified as commercial can support lodgepole pine forests (Alexander 1974, Green and Van Hooser 1983).

REACTION TO COMPETITION

Lodgepole pine is rated shade-intolerant (Baker 1949). t is comparable in shade tolerance to ponderosa pine, but is more intolerant than associates such as Rocky Mountain Douglas-fir, blue spruce (*Picea pungens* Engelm.), Engelmann spruce, and subalpine fir. However, it is not as intolerant as aspen (*Populus tremuloides* Michx.), another common associate.

Lodgepole pine is an aggressive pioneer and invader whose occurrence is largely a result of fire (Clements 1910, Lotan and Critchfield 1985, Stahelin 1943). Its successional status depends upon environmental conditions, history, and competition from associated species. Lodgepole pine is seral when it is a temporary occupant of the site. It is a minor seral where it is an overstory component of stands with a mixed composition and will be replaced in 50 to 100 years by more tolerant associates. Lodgepole pine is a dominant seral where it is an overstory with a vigorous understory of shade-tolerant associates. Replacement usually requires 100 to 200 years; but if mountain pine beetles (*Dendroctonus ponderosae* Hopk.) attack these stands and remove the larger pines, the time required for climax species to occupy the site is shortened. It is a persistent seral where stands are the result of catastrophic fires; and some areas have burned so often and so extensively that large acreages are nearly pure pine. In those situations, lodgepole pine is maintained on the area, because there is no seed source for the normal climax species. Lodgepole pine is a climax in those situations where it is held on the site by natural or artificial means, and therefore, is self-perpetuating (fig. 1) (Lotan and Critchfield 1985, Pfister and Daubenmire 1975). One example of a naturally stable lodgepole pine community is at lower elevations along the east slope of the Front Range, in northern Colorado. Douglas-fir, considered the climax species, no longer reproduces itself in stands dominated by lodgepole pine, because the sites have become too dry (Moir 1969).

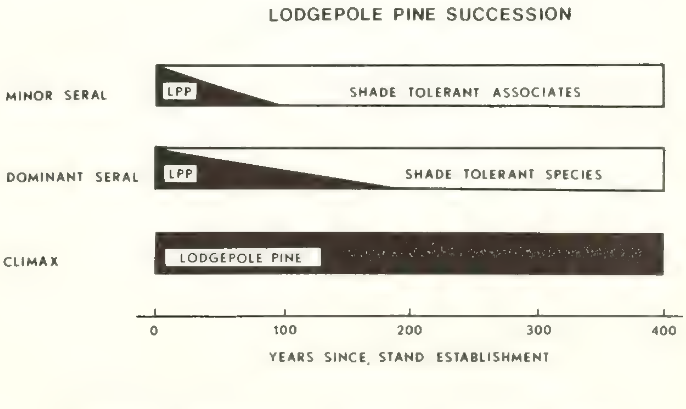


Figure 1.—Successional status of lodgepole pine.

STAND CONDITIONS

The lodgepole pine type is generally regarded as an even-aged, single-storied forest, varying in age from place to place but uniform in age within any given stand. This is true only where favorable fire, seed, and climatic conditions once combined to produce many seedlings at one time (Lexen 1949). Sometimes, under these conditions, lodgepole pine develops into overly dense, stagnated stands (fig. 2). Elsewhere, lodgepole pine grows on a wide range of sites with a great diversity of stand conditions. It can occur as two-aged, single- or two-storied stands; three-aged, two- or three-storied stands; and even-aged to broad-aged multi-storied stands (Tackle 1955). Spacing of these stands ranges from dense to open. Multi-storied stands, and to a lesser extent, two- and three-storied stands, generally originated from either scattered trees that produced seed for subsequent stand development, or the gradual deterioration of old-growth stands resulting from wind, insects, and diseases (Alexander 1975).

Lodgepole pine stands frequently are pure pine over much of the area occupied, especially where stands originated after repeated fires and there is no seed source for other species (Lotan and Critchfield 1985, Tackle 1961). However, mixed stands of lodgepole pine and other species are not uncommon, especially lodgepole pine, Engelmann spruce and subalpine fir, and lodgepole pine and Douglas-fir. In pure stands of lodgepole pine of medium to high density, there seldom is an understory of reproduction; in low-density stands there may be younger trees in the understory. If this advanced growth has not been suppressed for a long time, it will respond to release.

In mixed stands, the overstory either can be pure pine, or pine, spruce and/or fir at higher elevations, and pine and Douglas-fir at lower elevations, with the climax species in the understory. Advanced growth of the climax species will respond to release when the overstory is removed (Alexander 1975).

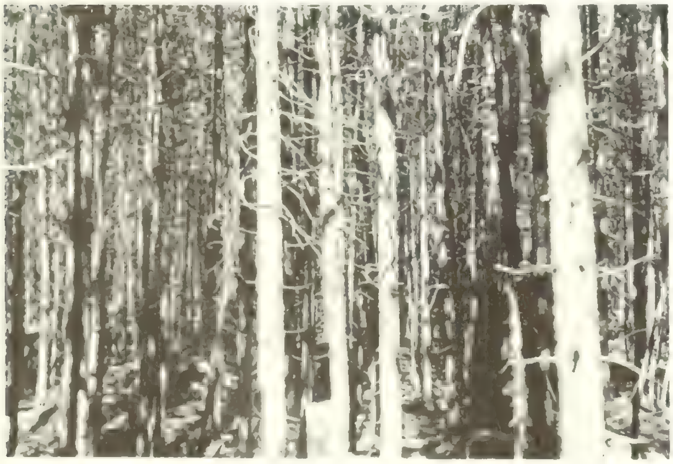
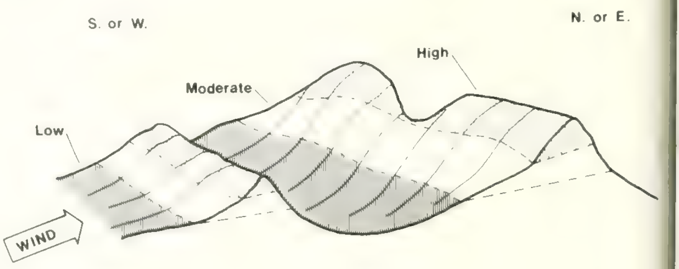


Figure 2.—Overly dense stagnated stand of lodgepole pine.

DAMAGING AGENTS

WIND

In the central Rocky Mountains, lodgepole pine i generally considered susceptible to windthrow after cu ting. Partial cutting increases the risk, because the en tire stand is opened up and, therefore, vulnerable. Les damage is associated with clearcutting, because only th boundaries between cut and uncut areas are vulnerabl (Alexander 1966, 1975; Mason 1915b). While the tenden cy to windthrow is frequently attributed to a shallow roo system, the development of the root system varies wit soil and stand conditions. On deep, well-drained soils trees have a better root system than on shallow or poor ly drained soils. With the same soil conditions, individua stems in denser stands are less windfirm, because tree that have developed together in dense stands over lon periods of time mutually protect and support each othe and do not have the roots, boles, and crowns to with stand exposure to the wind if they are opened u drastically. The risk of blowdown is also greater in stand with defective roots and boles. The presence of old wind falls is a good indication of lack of windfirmness. Fur thermore, regardless of how stands are cut or the so and stand conditions, the risk of blowdown is greate on some exposures than others. The following windfa risk situations based on exposure have been identifie (fig. 3) by Mason (1915b) and Alexander (1964, 1967 1975).



WIND RISK

Figure 3.—Wind risk in relation to topographic exposure.

Low

1. Valley bottoms except where parallel to the pre vailing winds, and all flat areas.
2. All lower and gentle middle north- and east-facin slopes.
3. All lower and gentle middle south- and wes facing slopes that are protected by considerabl higher ground not far to windward.

Moderate

1. Valley bottoms parallel to the direction of prevai ing winds.
2. All lower and gentle middle south- and wes facing slopes not protected to the windward.
3. Moderate to steep middle and all upper north- an east-facing slopes.
4. Moderate to steep middle south- and west-facin slopes protected by considerably higher groun not far to windward.

High

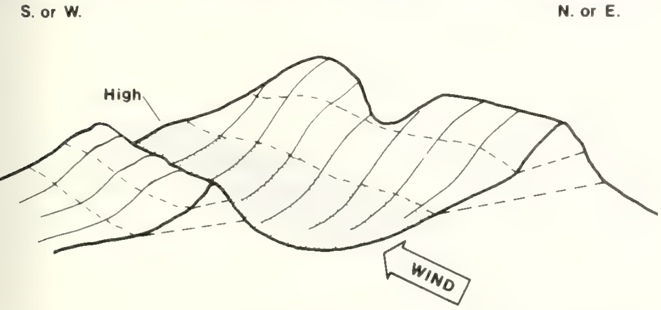
1. Ridgetops.
2. Moderate to steep middle south- and west-facing slopes not protected to the windward, and all upper south- and west-facing slopes.
3. Saddles in ridgetops.

The risk of windfall in these situations is increased at ɜast one category by factors such as poor drainage, hallow soils, and defective roots and boles. All situa-ons become high risk if the stands are exposed to pecial topographic situations such as valley bottoms /ith steep side slopes that are parallel to the wind and ecome narrower in the direction that the wind blows ig. 4), and gaps and saddles in ridges at higher eleva-ons to the windward that can funnel wind into the area ig. 5).

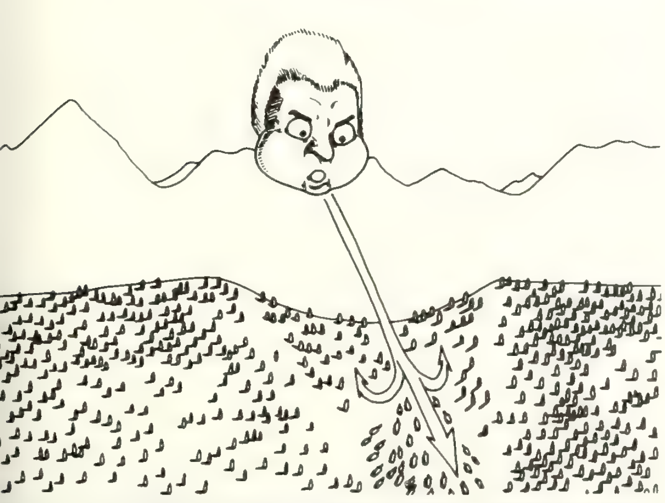
NSECTS

Bark Beetles

Many species of insects infest lodgepole pine (Keen 952); but the mountain pine beetle is the most serious est in mature to overmature lodgepole pine stands in e Rocky Mountains (Amman 1978). Epidemics have oc-urred throughout recorded history (Roe and Amman 970), and severe outbreaks have occurred in Wyoming nd northern Colorado (fig. 6), where several old-growth stands that were protected from wildfires reached a high degree of susceptibility to attack (Alexander 1975).



gure 4.—Very high wind risk; valley bottoms parallel to the direction of the wind.



gure 5.—Very high wind risk; winds funneled through saddle in a ridgetop.

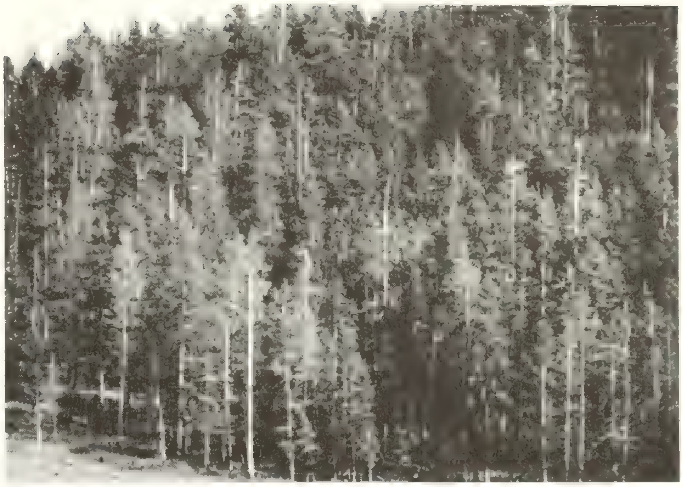


Figure 6.—Lodgepole pine attacked by mountain pine beetles.

Adult beetles attack lodgepole pine in July and August, introducing blue-stain fungi that hastens the death of the tree (Amman 1978). Beetles create egg galleries, mate, and deposit eggs in the phloem layer. Larvae then feed on the phloem and, in conjunction with blue-stain fungi, girdle and kill the tree. The first indications of attack are pitch tubes on the trunk where beetles have entered, and boring dust in the bark crevices and around the base of the tree. Trees attacked in the summer usually begin to fade the following spring. Needles change from green to yellow green, sorrel, and finally rusty brown before dropping off (McCambridge and Trostle 1972).

Not all stands are equally susceptible to attack. Epidemic outbreaks are usually associated with stands that contain (1) at least some vigorous medium- to thick-phloemed trees 14 inches in diameter and larger, (2) trees more than 80 years old, (3) trees with mean diameters larger than 8 inches, and (4) trees growing at elevations where temperatures are favorable to brood development (Amman 1978). As the larger trees are killed, the beetles attack smaller diameter trees until the outbreak finally subsides, because the phloem of these trees is not thick enough to provide a food supply. Trees smaller than 6 inches d.b.h. are rarely killed (Cole and Amman 1969). Although natural factors such as a sudden lowering of fall temperature or prolonged subzero winter temperatures, nematodes, woodpeckers, or parasites may reduce populations, they cannot be relied upon to control outbreaks (McCambridge and Trostle 1972).

Another potentially destructive bark beetle is the pine engraver (*Ips pini* Say.). Pine engraver populations commonly develop in logging slash, especially if it is shaded or does not dry quickly for some other reason. The most effective control is removing or burning large slash and exposing small slash to direct sunlight and wind so that it dries rapidly (Sartwell et al. 1971).

Other Insects

Other insects generally do not cause widespread losses but can be locally serious. These include the pandora moth (*Coloradia pandora* Blake) and the lodgepole pine terminal weevil (*Pissodes terminalis* Hopping) that produce distorted or forked crowns in young stands (Furniss and Carolin 1977).

DISEASES

Dwarf Mistletoe

Dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) is the most serious disease affecting lodgepole pine (Hawksworth 1965) (fig. 7). Surveys in Colorado and Wyoming show that about 50% of the commercial lodgepole pine forests are infected to some degree by dwarf mistletoe (Johnson et al. 1981). Infection in two Wyoming forests was greater than 60%. Dwarf mistletoe reduces growth, increases mortality (Hawksworth and Hinds 1964), and drastically reduces seed production. The mortality rate depends largely on the age of the host tree when attacked. Young trees die quickly, while older trees with well-developed and vigorous crowns may not show appreciable effects for years. Dwarf mistletoe is most damaging in stands that have been partially opened up by cutting, mountain pine beetles, or windfall, and is least damaging on areas regenerated after catastrophic fires (Hawksworth and Dooling 1984). Heavily infected old-growth stands frequently have only about 50% of the sawtimber volume of comparable uninfected stands (Hawksworth and Dooling 1984).

Dwarf mistletoe is a parasitic plant that flowers in April and May. At maturity (August and September), fruits are forcibly ejected for distances up to 30 feet, and in one study, about 40% of seeds produced were intercepted by trees (Hawksworth 1965). Seeds are covered with a gelatinous material, which acts as a lubricant when wet from rain and facilitates movement from pine needles onto branches where infection takes place (Hawksworth 1975). Rate of spread of mistletoe is slow—about 1.5 feet per year in open stands and 0.9 foot per year in dense, immature stands (Hawksworth and Dooling 1984, Hawksworth and Graham 1963).

The disease is difficult to detect in recently infected stands, because trees show no abnormalities except for the inconspicuous shoots on branches and main stems Where the parasite has been present for a long time stands have one or more heavily damaged centers characterized by many trees with witches' brooms, spike tops, and an above-average number of snags wit remnants of brooms (Hawksworth and Dooling 1984

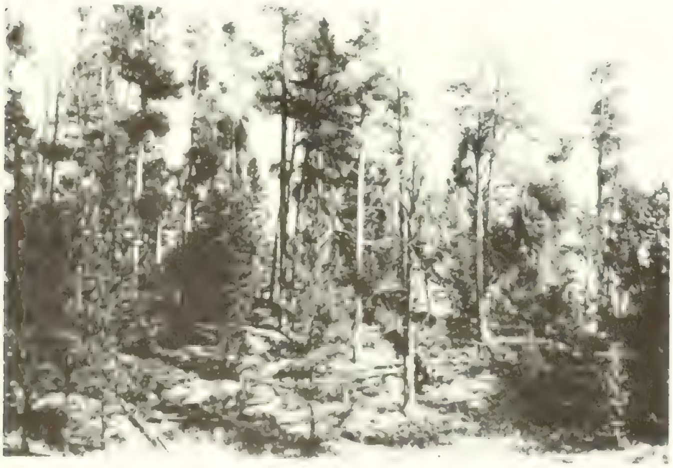
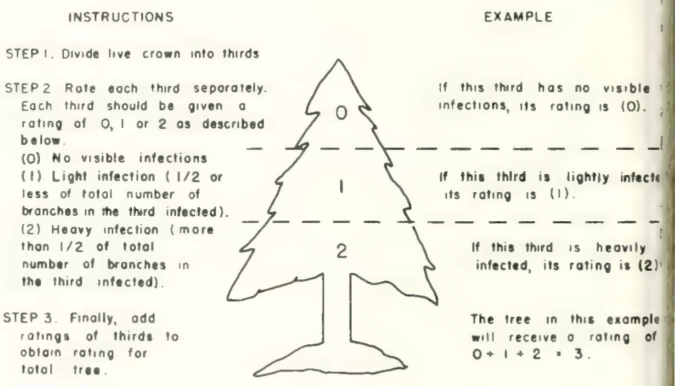


Figure 7.—Lodgepole pine infested with dwarf mistletoe.

Although optimum development is favored by vigorous host, and the most vigorous trees are mos heavily infected, frequency of infection is usually highe on poor than good sites. Furthermore, where site inde is 70 or greater (Alexander et al. 1967), only the middl and lower crowns of dominants and codominants ar susceptible to heavy infection, while trees in the intermediate or lower crown classes are susceptible t heavy infection throughout their crowns. Where the sit index is below 70, all crown classes are susceptible t heavy infection throughout the crowns. In Colorado an Wyoming, dwarf mistletoe has an altitudinal limit o about 300 to 500 feet below the upper limit of commercial lodgepole pine forests. This means that in som areas, considerable lodgepole pine is above the dwar mistletoe zone (Hawksworth and Dooling 1984).

To quantify the severity of infection, Hawkswort (1961, 1977) developed the 6-class mistletoe rating syste (fig. 8). The average stand rating can be estimated b determining the percentage of tree infection in the stand



INSTRUCTIONS

STEP 1. Divide live crown into thirds

STEP 2 Rate each third separately. Each third should be given a rating of 0, 1 or 2 as described below.
(0) No visible infections
(1) Light infection (1/2 or less of total number of branches in the third infected).
(2) Heavy infection (more than 1/2 of total number of branches in the third infected).

STEP 3. Finally, add ratings of thirds to obtain rating for total tree.

EXAMPLE

If this third has no visible infections, its rating is (0).

If this third is lightly infecte its rating is (1).

If this third is heavily infected, its rating is (2)

The tree in this example will receive a rating of 0 + 1 + 2 = 3.

Figure 8.—The six-class mistletoe rating system.

Average stand mistletoe rating	Percent of trees infected
1	50
2	70
3	90
4	97
5	99
6	100

Rust Fungi

Comandra blister rust, a canker disease caused by *Cronartium comandrae* Pk., commonly occurs in the centra Rocky Mountains; but damage has been most extensiv n northern Wyoming (Geils and Jacobi 1984, Peterson 1962). Girdling causes dead tops and flagging branches, which are the most conspicuous symptoms until dead rees begin to appear. On larger stem infections, cankers with an abundance of yellow, dried resin are a conspicuous symptom (Mielke et al. 1968). The disease cannot pass directly from pine to pine; it requires an inermediate host (*Comandra umbellata* (L.) Nutt.).

The damage from Comandra rust usually is not specacular; but trees of all sizes and ages are susceptible (Peterson 1962). Seedlings may be killed in a relatively short time. In older trees, the time between initial infecion and death may be 25 or more years, because the infection enters the trunk through the branches, and the rate of spread is slow. Under conditions favorable to the rust, stands may be heavily damaged over limited areas. In those stands, 50% or more of the living and dead trees have cankers, and about 50% the cankered trees have spike-tops (Geils and Jacobi 1984, Krebill 1965). However, the infection usually is lighter and scattered through the stand (Peterson 1962).

Sanitation salvage cutting is about the only practical way of controlling the disease in forest stands (Mielke et al. 1968). In areas of high tree values, it may be possible to prune infected branches from lightly infected trees; but heavily infected trees should be cut.

Western gall rust (*Peridermium harknessii* Moore) occurs on lodgepole pine throughout the Rocky Mountains, but is not as distinctive as Comandra rust, because most nfections occur as galls on branches rather than on the runk. However, when stem infections occur, they usually result in hip cankers. Trees frequently are broken off by the wind at the point of infection. Mortality in the eedling stage, loss of growth, and cull are the principal orms of damage from this rust. Removal of infected trees n silvicultural operations is the only practical way to ontrol gall rust damage in forests. Presence of a few galls is not sufficient cause to remove a tree. Only cankered trees need be cut (Peterson 1960).

Other Diseases

The major root and butt fungi attacking lodgepole pine n the Rocky Mountains are *Polyporus circinatus* Fr., *Coniophora puteana* (Schum:Fr.) Karst, and *Armillaria mellea* (Vahl.:Fr.) Quel.; the principal trunk rot fungus s *Phellinus pini* (Thore:Fr.) Karst (=*Fomes pini* Thore:Fr.) Lloyd) [(Fr.) Karst)] (Hepting 1971, Hornibrook 1950).

As old-growth is converted to managed stands, decay ungi can be expected to decrease. Early removal of odgepole pine with known indicators of defect will help stablish healthy, vigorous forests with greater growth otential. Rot losses in future stands can be minimized by shorter cutting rotations, such as 120 years or less. lose supervision of logging operations to reduce mechanical injuries will minimize courts of entry for ecay fungi. Proper slash disposal will lower inoculum otential of rot fungi in residual stands. These sanitaion measures are important because direct control of ots is seldom feasible or economical.

FIRE

Fire has had a profound effect on the structure and composition of lodgepole pine forests. Succession to "climax" species is frequently interrupted by fire. As a result of fire, lodgepole pine often exists in extensive, pure stands, because there is little or no seed source of associated tree species. Thus, replacement of lodgepole pine is slow. The effects of fire, fuel accumulation, stand development, and insects and diseases in lodgepole pine are all part of a set of complex biological and physical relationships that control the establishment and maintenance of stands (Lotan and Perry 1983).

The effect of fire on the structure and composition of a lodgepole pine stand depends greatly on its intensity. Fires in lodgepole pine vary from surface fires of low intensity to crown fires of high intensity. High-intensity fires destroy the residual stand and may result in a heavy seeding from serotinous cones. If the old stand contains enough trees with serotinous cones, a dense, even-aged, young stand usually results. Occasionally, fires may be intense enough to destroy cones, resulting in a thinly stocked stand. Low-intensity surface fires may kill advanced reproduction of other species, but leave at least some residual lodgepole pine, which results in an uneven-aged stand. Fire frequency may vary from 20 to 500 years (Lotan and Perry 1983).

ANIMALS

Animals rarely damage established lodgepole pine. Mule deer (*Odocoileus hemionus* Rafinesque) and elk (*Cervus elaphus* L.), when yarded up in the winter, may browse lodgepole pine, but only as a last resort. Bears (*Ursus* spp.) and procupines (*Erethizon dorsatum* Brandt) occur in lodgepole pine forests but seldom damage trees, except locally.

CUTTING HISTORY

The first cuttings in lodgepole pine forests occurred in the late 1800s. Some of the earliest were clearcuttings to provide stulls, lagging, and charcoal for mining operations. Pioneer ranchers used lodgepole pine for fuel, fences, and corrals. Later, millions of cross ties were hewn for the railroads. Following World War I, a form of partial cutting became standard practice on the national forests of the central Rocky Mountains, even though early studies suggested that clearcutting satisfied the silvical requirements of the species (Bates et al. 1929, Clements 1910, Mason 1915a). The usual practice was to mark stands for the selective removal of special products such as ties, posts, poles, and sawlogs. Cutting often was heavy, because everything salable usually was marked for removal. Most skidding was done with horses. Seedbed preparation was limited to the disturbance associated with logging and slash disposal. Slash either was lopped and scattered or piled and burned (Thompson 1929).

Generally, partial cutting, especially when more than 50% of the total basal area was removed, was not a successful means of arresting deterioration in old-growth stands or accelerating growth of the residual stand. For example, residual trees on the Fraser Experimental Forest suffered heavy mortality when about 60% of the total basal area was removed by either individual tree selection or modified seed-tree cutting (Alexander 1966b) (fig. 9). Furthermore, net increment was less than in uncut stands. Similar results followed heavy partial cutting elsewhere in the central Rocky Mountains, and in the northern and Canadian Rockies (Blyth 1957, Hatch 1967, LeBarron 1952). Even where mortality was not a serious problem, heavy partial cutting often left the older, decadent stands in such poor condition that not only was there little or no growing stock available for another cut, but the stands had little appearance of permanent forest cover (Tackle 1965).

Where substantial reserve volumes were left, partial cutting was successful in some instances in the sense that the residual stand did not blow down. On the Fraser Experimental Forest, windfall losses were light and other mortality was negligible after partial cutting removed about 45% of the total basal area in old-growth lodgepole pine stands by a modified shelterwood cut, even though the stands were exposed to windstorms that nearly destroyed adjacent, partially cut stands where 60% of the total basal area was removed (Alexander 1966b). Net increment was no greater than in uncut stands, however.

There are numerous examples of early cuttings on many national forests in Colorado and Wyoming, where a light to moderate shelterwood cut that removed 30% to 40% of the total basal area did not result to excessive mortality. The openings created have regenerated to either new lodgepole pine or the climax species—Engelmann spruce and subalpine fir. Where dwarf mistletoe infection in overstory trees was light, the new pine stand was not heavily infected (Alexander 1975).

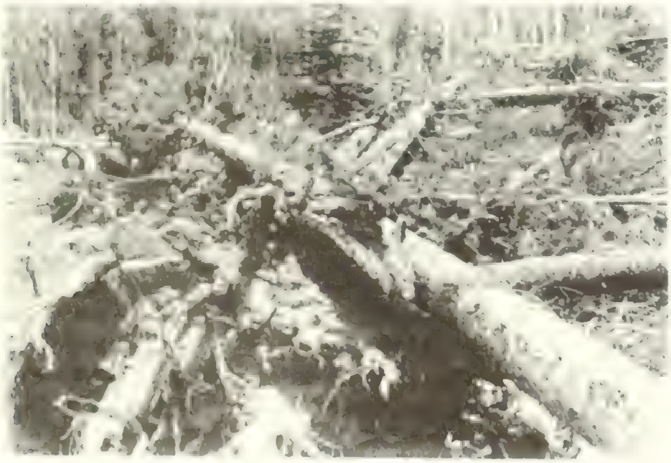


Figure 9.—Heavy blowdown in lodgepole pine after partial cutting that removed 60% of the basal area in the first entry, Fraser Experimental Forest, Colorado.

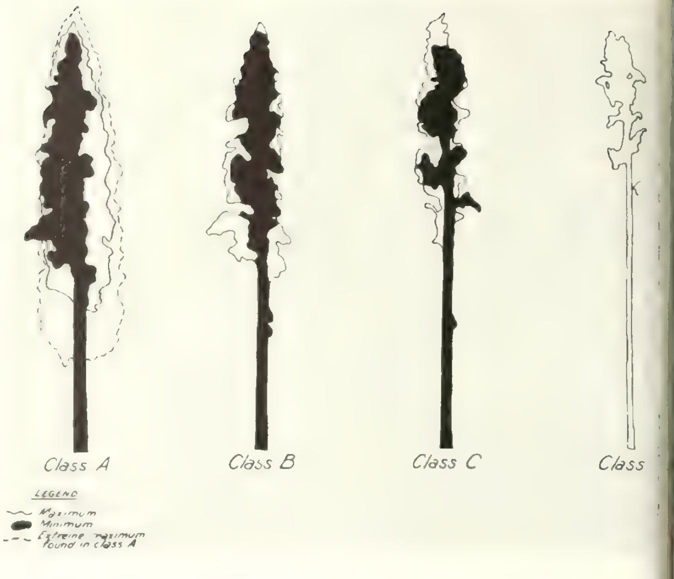


Figure 10.—Lodgepole pine tree vigor classes.

In 1939, Taylor developed a tree classification scheme for marking lodgepole pine for partial cutting that is still useful (fig. 10). He based his classification on the area, length, and vigor of the crowns of individual trees. Tree marked for removal should come from the lower vigo classes.

Vigor class A

1. Crown area: 30% or more of the "extreme outline of vigor class A.
2. Crown length: 50% or more the bole length.
3. Crown vigor: Dense, full, good color, pointed.

Vigor class B

1. Crown area: Usually more than 30% but less tha 50% of the "extreme outline" of vigor class A.
2. Crown length: Usually more than 50% but usuall less than 60% of the bole length.
3. Crown vigor: Moderately dense, good colo pointed or slightly rounded.

Vigor class C

1. Crown area: 15% to 30% of the "extreme outline' of vigor class A.
2. Crown length: 40% to 50% of the bole length ex cept for trees with above average vigor, when 20% of the bole length is sufficient.
3. Crown vigor: Sparse, bunchy, poor color, neve pointed.

Vigor class D

1. All live trees of poorer vigor than class C. Include trees in classes A, B, and C outlines but with dea or dying tops.

At the close of World War II, harvesting shifted bac to clearcutting (LeBarron 1952, Lexen 1949). Traditiona ly, stands were clearcut either in blocks or strips (Alex ander 1966b, LeBarron 1952, Lexen 1949, Tackle 1965 The pattern and size of opening depended upon th predominant cone habit (serotinous or nonserotinous and the occurrence of dwarf mistletoe (Tackle 1965). Th common practice has been to cut all merchantable trees followed by removal of the unmerchantable residual t reduce dwarf mistletoe infection. Slash and loggin debris usually were either (1) broadcast burned, doze piled, or windrowed and burned, or (2) roller choppe o reduce fire hazard and prepare seedbeds. Clearcuts usually restocked naturally if logging slash bearing erotinous cones was carefully handled or openings were mall where cones were nonserotinous (Alexander 1966a, Tackle 1964, 1965). However, both artificial and natural regeneration efforts failed where seed was burned in slash fires, openings were too large to be eeded in from the side, or opening up the site created difficult microenvironments (USDA Forest Service 1971).

REGENERATION SILVICULTURAL SYSTEMS

Old-growth lodgepole pine forests are generally harvested by clearcutting, shelterwood, and group selecion cutting, and by modifications of these methods. Seed-tree cutting usually is not applicable as a regeneraion method because of susceptibility of residual trees o windthrow. Although the silvical characteristics of odgepole pine do not readily lend themselves to individual tree selection cutting, it can be used in areas where vertical diversity and different tree sizes intermingled on the same site are desired (Alexander 1974, Alexander et al. 1983). The objective of each regeneraion system is to harvest the timber crop and obtain adequate reproduction. The choice of cutting method in odgepole pine stands depends upon management goals; but stand conditions, windfall, disease and insect suscepibility, and the risk of potential fire damage that vary from place to place limit the options available for handling individual stands. Furthermore, the economics of harvesting, manufacturing, and marketing wood products from many small diameter trees in the central Rocky Mountains has further limited cutting practices. Cutting o bring old-growth lodgepole pine under management may be a compromise between what is desirable and what is possible. Management on many areas may involve a combination of clearcutting small areas, several partial cutting treatments, and no cutting (Alexander 1974, 1975).

EVEN-AGED CUTTING METHODS

Clearcutting is the preferred even-aged method for old-growth lodgepole pine and has been used almost exclusively since the end of World War II because of several factors. (1) Lodgepole pine, a pioneer species, is shade-intolerant and reproduces best in most instances when overstory competition is removed or drastically reduced. (2) Dwarf mistletoe—present in many stands in varying degrees—is best controlled by separating the old stand from the new. (3) Windfall and mountain pine beetles, while variable, are always a threat. (4) The potenial for future growth is limited because of the generally ow vigor of mature and overmature stands and the suppressed condition of many smaller trees. Furthermore, many natural stands appear to be even-aged, having developed after catastrophic fires or other disturbances.

Shelterwood cutting in lodgepole pine is applicable in stands where (1) management objectives or environmental constraints preclude clearcutting and dwarf mistletoe infection is low, (2) regeneration requirements include overstory shade and an on-site seed source, or (3) a manageable stand of advanced regeneration exists.

Management with Advanced Regeneration

Simulated Shelterwood Cutting

This cutting method removes the overstory from a manageable stand of advanced reproduction in one or more operations. It simulates the final harvest of a standard shelterwood.

There seldom is a manageable stand of advanced regeneration under pure lodgepole pine, or if one is present, it has been suppressed for so long that it has no future management potential. In mixed stands, where the associated species are spruce and fir, there frequently is a stand of advanced reproduction. These trees will respond to release after cutting; but wide variations in age, composition, quality, and quantity of advanced reproduction require careful evaluation of the potential for future management. One course of action is followed if the advanced reproduction is to be managed, another if a manageable stand is not present, cannot be saved, is not expected to grow well, or the manager chooses to destroy it and start over.

Prelogging evaluation.—The initial examination must answer the following questions: (1) How much of the area is stocked with acceptable seedlings and saplings, and will that stocking insure a satisfactory replacement stand? (2) Can it be logged economically by methods that will save advanced reproduction? Is the timber volume too heavy to save advanced reproduction if it is removed in one cut? (3) How much of the area will require subsequent natural or artificial regeneration, either because advanced reproduction is not present or will be damaged or destroyed in logging?

Because any kind of cutting is likely to destroy at least 50% of the advanced spruce and fir growth in mixed lodgepole pine stands, a manageable stand of advanced reproduction before cutting should contain at least 600 acceptable seedlings and saplings per acre, at least 50% of which should be spruce. There are few data available on the growth response of advanced reproduction after release in the central and southern Rocky Mountains, but in the Intermountain Region, McCaughey and Schmidt (1982) found that both advanced spruce and fir made good height growth after clearcutting and partial cutting in spruce-fir stands. The following criteria, therefore, are based largely on experience and observation. To be acceptable, reproduction must be of good form, able to make vigorous growth when released, and be free of defect or mechanical injury that cannot be outgrown. Trees larger than 4 inches d.b.h. may be acceptable; but they should not be included in the prelogging regeneration survey because they are more likely to be damaged or destroyed in logging or windthrown after logging. Stands or portions of stands not meeting these criteria have to be restocked with subsequent natural or artificial regeneration.

Cutting and slash disposal treatment.—Mature and overmature trees should be cut to release advanced spruce and fir reproduction and harvest merchantable volume. Seed sources need not be reserved from cutting unless required for fill-in stocking. The size, shape, and arrangement of units cut is not critical for regeneration; but to be compatible with other key uses, they should be irregular in shape and blend into the landscape. Not more than one-third of any drainage or working circle should be cut over at any one time.

Protection of advanced reproduction begins with a well-designed logging plan. Logging equipment and activity must be suited to the terrain and rigidly controlled to minimize damage of advanced reproduction and disturbance to soil. Skid roads should be located at least 200 feet apart and marked on the ground before cutting. Skidding equipment should be moved only on skid roads. Where possible, trees should be felled into openings at a herringbone angle to the skid road to reduce disturbance when logs are moved onto the skid road. It may be necessary to deviate from a herringbone felling angle in order to drop the trees into openings. In this case, the logs will have to bucked into short lengths to reduce skidding damage. Furthermore, the felling and skidding operations must be closely coordinated, because it may be necessary to fell and skid one tree before another is felled. Dead sound material and snags that are felled should be skidded out of the area to minimize the amount of slash and unmerchantable material. In stands with heavy volumes per acre, it may be necessary to remove the overstory in more than one cut.

Slash treatment then should be confined to areas of heavy concentrations as required for protection from fire and insects or preservation of esthetic values. Slash also must be treated carefully to avoid damage to advanced reproduction. If trees are felled into openings as much as possible, a minimum of turning and travel with brush dozers will be needed to concentrate the slash for burning. Slash piles should confine burning to the smallest total area possible.

Postlogging reevaluation.—Even with careful logging and slash treatment, some advanced reproduction will be damaged or destroyed. The area must be surveyed to: (1) Determine the extend of damage to the reproduction. In mixed lodgepole pine stands, at least 300 acceptable seedlings and saplings per acre, of which at least 50% should be spruce, must have survived to consider the area adequately stocked. This is in addition to any trees larger than 4 inches d.b.h. that survived. Areas that do not meet these standards will need fill-in or supplemental stocking. (2) Plan stand improvement—cleaning, weeding, and thinning—to release crop trees. Cutover areas should not be considered in an adequate growing condition until the crop trees are free to grow and the necessary fill-in planting or natural regeneration is complete. It is especially important to remove larger regeneration that has been broken off or has basal wounds. These trees can occupy considerable area and eventually become culls because of damage and decay.

Management for Natural Regeneration After Cutting

Clearcutting

This method harvests the timber crop in one step to establish a new stand. Because much of the lodgepole pine type in the central Rocky Mountains has little potential for future management because of advanced age relatively slow growth, and susceptibility to wind diseases, and insects, forest managers concerned with timber production have usually decided to convert old growth to managed stands by clearcutting in strips patches, and blocks (fig. 11). Therefore, harvesting and regeneration practices developed in the central Rocky Mountains have been directed toward this objective.

Cutting unit layout, logging plans, slash disposal, and seedbed treatment should be designed to (1) facilitate seed dispersal, (2) promote seedling survival and establishment, and (3) create favorable growing conditions If natural regeneration fails, plans must be made to use artificial regeneration. Clearcutting can be readily adapted to multiple-use land management by judicious selection of size, shape, and arrangement of openings in combination with other high-forest cutting practices (Alexander 1974, Alexander et al. 1983).

Size of opening.—Successful natural regeneration of lodgepole pine depends upon an adequate supply of seed falling on a receptive seedbed. In the central Rocky Mountains, there are no data on seed:seedling ratios; but Lotan and Perry (1977) estimated seedling survival in relation to number of sound seeds on different seedbeds in the Targee National Forest, Idaho, for an *Abies lasiocarpa/Vaccinium scoparium* habitat type. They estimated that the number of sound seeds required to produce 1,200 5-year-old seedlings per acre—a desirable stocking goal—in relation to seedbed treatments on these cool moist sites was as follows.

Seedbed treatment	**Number of sound seeds for 1,200 seedlings**
Natural undisturbed	615,000
Piled and burned	560,000
Disked with lightweight harrow	95,000
Stand scalped to simulate dozer scalping	185,000
Hand scalped and cultivated	40,000
Hand scalped, cultivated, and sprayed with dalapon	75,000
Simulated brushblade scarification	65,000
Furrowed-vertical sides	35,000
V-shaped trenched	60,000

The size of opening that is likely to receive sufficient seed to restock receptive seedbeds is influenced by whether the seed is dispersed by open or closed cones The manager cannot assume that the cone habitat is either serotinous or nonserotinous. Each area must be examined and each stand classified as (1) closed cone (90% or more of the cones on individual trees are closed), (2) open cone (10% or less of the cones on individual trees are closed), or (3) intermediate (less than 90% but more than 10% of the cones on individual trees are closed). If the stand is classified as closed cone, the manager must then determine if there is enough sound seed stored in closed cones to provide an adequate seed source for natural regeneration, using the procedures developed by Lotan and Jensen (1970).

The size and shape of openings cut in stands with serotinous cone habitat that will restock is highly flexible if there is enough seed. Natural regeneration is a one-shot opportunity, however, because the seed supply is in the slash-borne cones, and nearly all cones will open in the first 2 years after cutting. There is no advantage to cutting openings larger than 30 to 40 acres, even for dwarf mistletoe control, and openings 10 to 20 acres would be more compatible with other uses (fig. 12). On south slopes and other difficult regeneration areas, it may be desirable to cut openings smaller than 10 acres to provide a supplemental seed source in trees standing around the perimeter. If there is not an adequate supply of seed in closed cones, the recommendations following apply.

In stands with nonserotinous or intermediate cone habitat, the cutting unit must be designed so that seed from the surrounding timber margin reaches all parts of the opening, unless artificial regeneration is planned. Effective seed dispersal distance from standing trees has not been studied in the central Rocky Mountains; but studies elsewhere, summarized by Lotan and Perry (1983), indicate that, with favorable seedbed and environmental conditions, the effective seeding distance in lodgepole pine is about 150 to 200 feet. The maximum width of opening likely to restock to natural reproduction, therefore, is 300 to 400 feet, or about five to six times tree height. Furthermore, it is not likely that only one seed crop will provide sufficient seedfall for adequate stocking. On south slopes, openings should be smaller—150 to 200 feet wide or about two to three times tree height. If larger openings are cut, plan on planting the area beyond effective seeding distance.

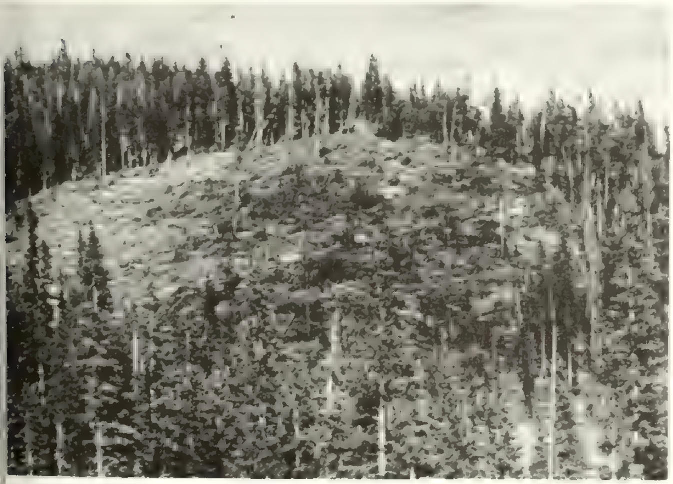


Figure 11.—Clearcut patch in a lodgepole pine stand on the Fraser Experimental Forest.

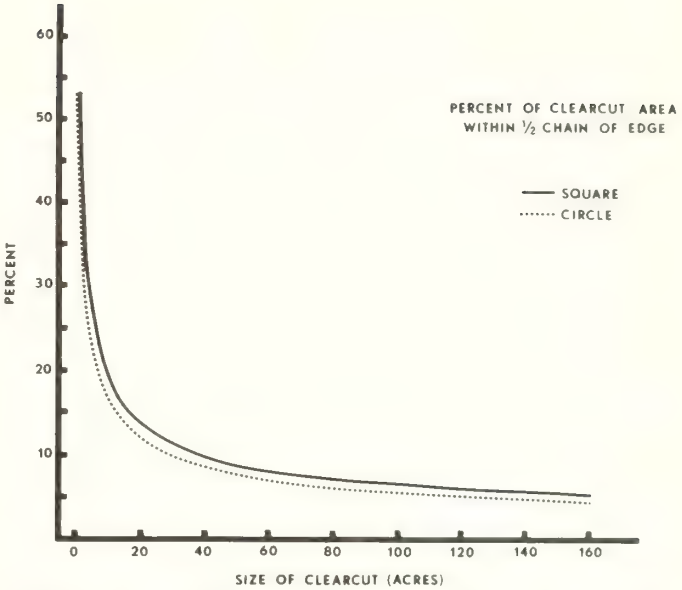


Figure 12.—Amount on area clearcut in relation to perimeter.

Windfall.—The following guidelines for minimizing windfall around the perimeter of clearcut openings were developed in Colorado (Alexander 1964, 1967, 1974).

1. Protection from wind for the vulnerable leeward boundaries is most important.
2. Do not locate cutting boundaries where they will be exposed to accelerated winds funneling through saddles in ridges to the south and west of the cutover area, especially if the ridges are at high elevations (fig. 5).
3. Avoid locating cutting boundaries on ridges or directly below saddles in ridges (fig. 13), especially ridgetops of secondary drainages to the lee and at right angles to the main drainage when the latter is a narrowing valley with steep slopes. One cutting unit should straddle each ridgetop and extend downslope in both directions for a distance of at least 200 feet. That unit may be cut or uncut. Such an arrangement will avoid leaving a cutting boundary on the top of a ridge (fig. 14).
4. Where topography, soils, and stand conditions permit, lay out each unit so that the maximum amount of cutting boundary is parallel to the contour or along a road (fig. 15).
5. Do not lay out cutting units with dangerous wind-catching indentations (fig. 16) or long, straight lines and square corners in the leeward boundary or in boundaries that are parallel to storm winds. V- or U-shaped identations in the boundary can funnel wind into the reserve stand. Long, straight cutting boundary lines and square corners also deflect the wind and cause increased velocities where the deflected currents converge like a windstream flowing over a crest. Irregular cutting boundaries without sharp identations or square corners lessen the opportunity for deflection and funneling of air currents.

6. Do not locate boundaries on poorly drained or shallow soils. Trees grown under these conditions are shallow rooted and susceptible to windthrow.
7. Locate cutting boundaries in stands of sound trees. Trees with decayed roots and boles or root systems that were cut or torn during road building or log skidding operations are poor windfall risks.
8. Locate cutting boundaries in immature stands when possible. Stands of young trees usually are less easily uprooted by strong winds.
9. Locate cutting boundaries in poorly stocked stands. Open-grown trees are more windfirm than trees grown in dense stands.
10. Avoid locating cutting boundaries in areas where there is evidence of old prelogging blowdowns.
11. Reduce blowdown in areas with exceptionally hazardous windfall potential by locating the vulnerable leeward boundaries where hazards are below average, or by eliminating those boundaries by progressive cutting into the wind.

Slash treatment and site preparation.—In stands with serotinous cones, careful handling of slash is required (1) to avoid destruction of seed-bearing cones; (2) heavy concentrations of slash obstruct seedling establishment and are a fire hazard; and (3) slash creates an adverse visual impact (Alexander 1974).

In stands with serotinous cone habit, dozer piling or windrowing dry slash over the entire area usually results in overly dense stands of reproduction, because abundant seed is shaken out of cones onto exposed mineral soil seedbeds (Alexander 1966a, Tackle 1964). Dozer piling and windrowing slash, then burning the concentrated slash, frequently results in poor stocking, especially when the slash fires burned over much of the area and destroyed most of the seed or created enough heat in the soil to inhibit any kind of plant growth for a long time. Broadcast burning usually results in little or no restocking, because most of the seed is destroyed. Disposal of slash by lopping and scattering, and by rolling and chopping have resulted in adequate restocking, if sufficient mineral soil (about 40% of the area) has been exposed and the seed-bearing cones are placed near the ground. Fire hazards and visual impact are usually not reduced sufficiently, however.

Concentrations of slash must be treated. If these concentrations are piled or windrowed for burning, the piles and windrows must be kept small (1/20 acre or less) and well distributed so that the burned area does not occupy more than 25% of the total area. The lighter areas of slash—less than 40% of the area covered with slash less than 1 foot deep—either can be lopped and scattered or rolled and chopped. This combination of treatments will reduce fire hazards and visual impact, provide exposed mineral soil, scatter the cone-bearing slash over the area, and place the cones near or on the ground (Alexander 1974).

In stands with nonserotinous or intermediate cone habit, slash can be handled in the same way as in stands with serotinous cones, or it can be broadcast burned. If slash is piled or windrowed for burning, the piles should be kept small and well distributed, because burning in

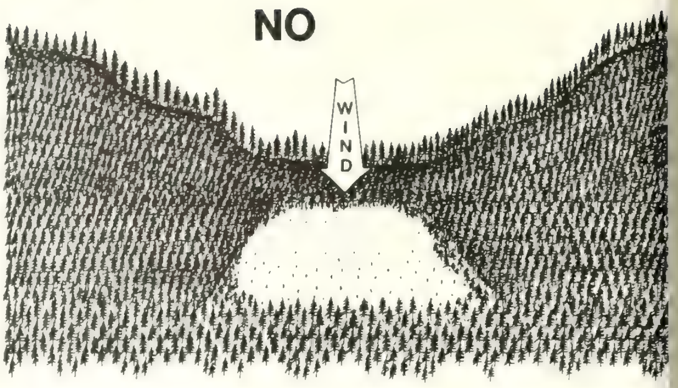


Figure 13.—Clearcut opening directly below a saddle where wind vortexing can occur and increase blowdown risk.

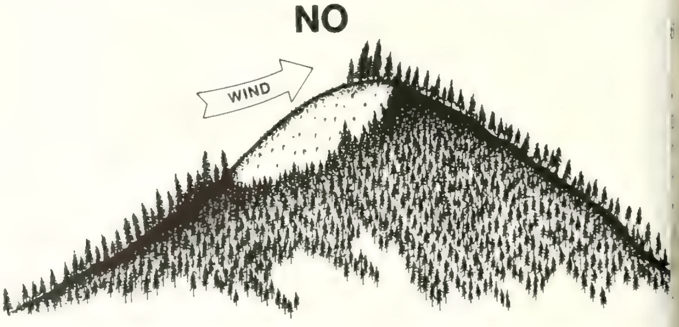


Figure 14.—Clearcut unit boundary on a ridgetop where risk of blowdown is increased.

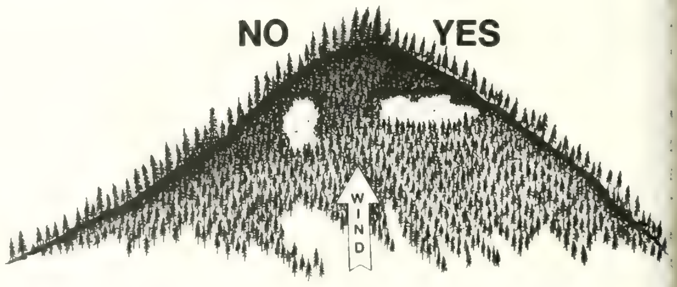


Figure 15.—Clearcut unit boundaries laid out across the slope that exposes the short dimensions of the unit to the wind helps reduce blowdown.

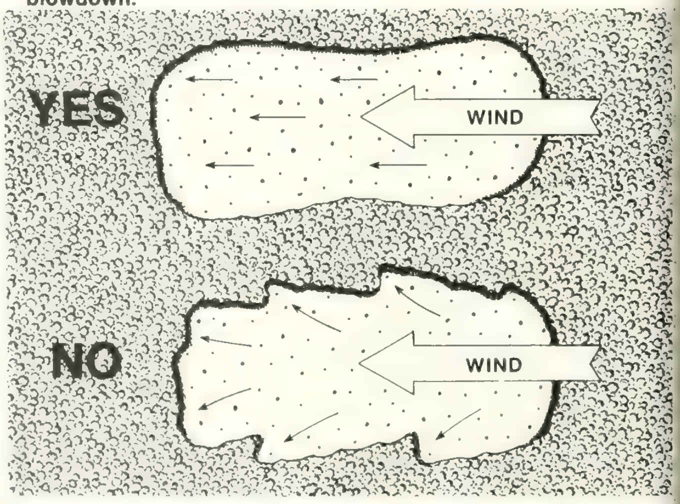


Figure 16.—Irregular cutting boundaries with sharp indentations or square corners help reduce blowdown.

ge concentrations often heats the soil enough to in- bit subsequent plant growth. To be effective, broadcast rning should cover about 75% of the area. It should nsume most, but not necessarily all, of the logging ush, other debris, and duff or organic material on the ound, and it should burn hot enough to destroy most the competing vegetation. It should not burn so hot, wever, that a deep layer of loose ash accumulates. eas with light slash can be lopped and scattered or lled and chopped. It may be necessary to do some ad- tional mechanical scarification on lopped and scat- red areas. Tractors with brush blades should be used, d about 40% of the area should be left with exposed ineral soil (Alexander 1974).

helterwood Cutting

This regeneration cutting method harvests a timber and in a series of cuts. In a standard shelterwood, the ew stand regenerates under the shade of a partial verstory canopy. The final harvest removes the shel- rwood and permits a new stand to develop in the pening. In a group shelterwood (a modification of the helterwood method), the new stand regenerates in small penings that leave standing trees around the margins s a seed source. Openings are too small (2 acres or less) be classified as a clearcut. This kind of cutting has een incorrectly called a modified group selection, but ffers from a selection cut in the way the growing stock regulated.

These cutting methods may be the only even-aged op- ons open to the manager where (1) multiple use con- derations preclude clearcutting, (2) combinations of nall cleared openings and high forests are required to eet the needs of various uses, or (3) areas are difficult regenerate after clearcutting. However, shelterwood utting requires careful marking of individual trees or roups of trees to be removed, and close supervision of gging. The following recommendations for shelter- ood cutting practices are keyed to broad stand descrip- ons based largely on experience, windfall risk situa- ons, and disease and insect problems (Alexander 1974, 975). Stands are pure pine unless otherwise indicated.

Single-storied stands.—These may appear to be even- ged (fig. 17), but often contain more than one age class, ccasionally may even be broad-aged. Codominants form e general level of the canopy; but the difference in eight between dominants, codominants, and intermedi- es is not as great as in spruce-fir stands. If stands are en-aged in appearance, there is a small range in ameter class and crown length; live crown length of minants and codominants is generally short to edium (30% to 60% of the total height and boles are enerally clear for 10% to 40% of total tree height); and ere are few coarse-limbed trees in the stand.

With two or more age classes, the younger trees usually ave finer branches, smaller diameter, longer live crown, d less clear bole than older trees. Stocking is general- uniform. A manageable stand of advanced reproduc- on is usually absent. In mixed stands, the overstory is either pure pine, or pine and Engelmann spruce, subalpine fir, or Douglas-fir, with advanced reproduction of species other than pine that may or may not be a manageable stand.

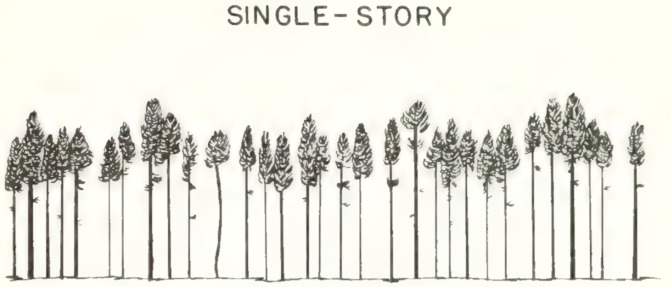


Figure 17.—A single-storied lodgepole pine stand.

Single-storied stands usually are the least windfirm, because trees have developed together over long periods of time and mutually protect each other from the wind.

If windfall risk is low and stands are uniformly spaced, the first cut can remove about 30% of the basal area on an individual tree basis (fig. 18). This initial entry is a preparatory cut that resembles the first step of a three-cut shelterwood, because it probably does not open up the stand enough for significant pine reproduction to become established. Overstory trees are all about equally susceptible to blowdown; therefore, the general level of the canopy should be maintained by removing some trees in each overstory crown class. The cut should come from C and D vigor class trees; but openings larger than one tree height in diameter should be avoided by distributing the cut over the entire area. Do not remove dominant trees that are protecting other trees to their leeward if these latter trees are to be reserved for the next cut. In mixed stands, if the overstory is mostly pine, handle it as a pure stand; if the overstory is of mixed composition, cut as much of the basal area recommended in pine as is possible to release the climax species.

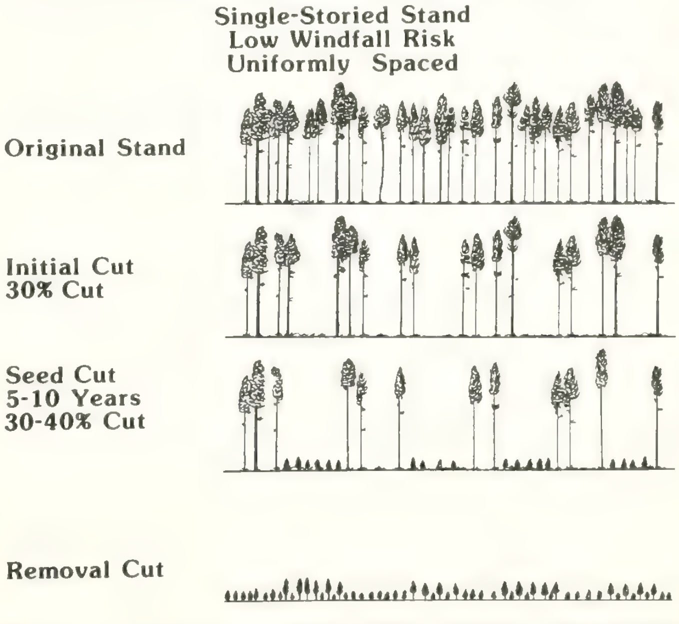


Figure 18.—Sequence of entries with a three-cut shelterwood in a uniformly-spaced, single-storied lodgepole pine in a low wind risk situation.

The second entry into the stand should not be made until 5 to 10 years after the first cut in order to determine if the residual stand is windfirm. The second cut should remove 30% to 40% of the original basal area on an individual tree basis. It simulates the second or seed cut of a three-step shelterwood. The largest and most vigorous dominants and codominants should be reserved as a seed source in stands with the nonserotinous or intermediate cone habit; but avoid cutting openings in the canopy larger than one tree height in diameter by distributing the cut over the entire area even if it means leaving trees in the C and D vigor classes with poor seed production potential. In mixed stands, cut as much of the recommended basal area in pine as is possible without creating openings larger than one tree height.

The last entry into these uniformly-spaced stands is the final harvest, which should remove all of the remaining original overstory. It should not be made until a manageable stand of reproduction has become established; but the cut should not be delayed beyond this point if timber production is the primary concern, because the overwood (1) hampers the later growth of seedlings, and (2) if infected with dwarf mistletoe, it will reinfect the new stand (fig. 19).

The manager also has the option of removing less than 30% of the basal area at any entry and making more entries; but they cannot be made at more frequent intervals. The cut will be spread out and continuous high forest cover maintained for a longer period of time. This option is not recommended where mountain pine beetles and dwarf mistletoe impose limitations on how stands can be handled.

The usual uniform arrangement of individual trees in single-storied stands is not well adapted to removing trees by groups. Occasionally, however, natural openings occur when stands begin to break up. Also, small openings may be desirable to meet management objectives.

If windfall risk is low but trees grow in clumps or spacing is irregular, an alternative to removing trees on an individual basis would be to remove about 30% of the basal area using a group shelterwood (fig. 20). Openings should be kept small, not more than one to two times tree height in diameter; not more than one-third of the area should be cut over at any one time. All trees in a clump either should be cut or left, because they mutually support each other, and removing only part of a clump is likely to result in windthrow of the remaining trees. This kind of cutting should be used only in stands where insect and disease problems are minimal.

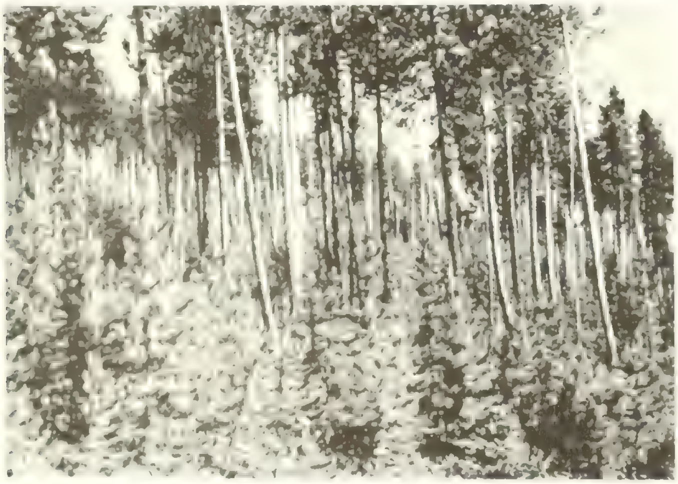


Figure 19.—New reproduction established after the seed cut of a three-cut shelterwood in lodgepole pine.

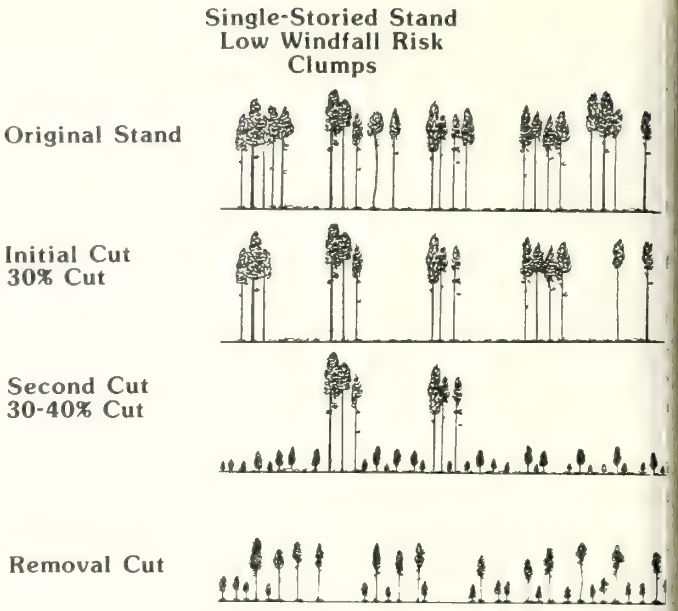


Figure 20.—Sequence of entries with a group shelterwood in an irregularly-spaced, single-storied lodgepole pine in a low wind risk situation.

The second entry into the stand should not be made until the first openings have been regenerated. This cut should remove about 30% to 40% of the original basal area without cutting over more than an additional one-third of the area. Openings should be no closer than about one to two tree heights to the original openings.

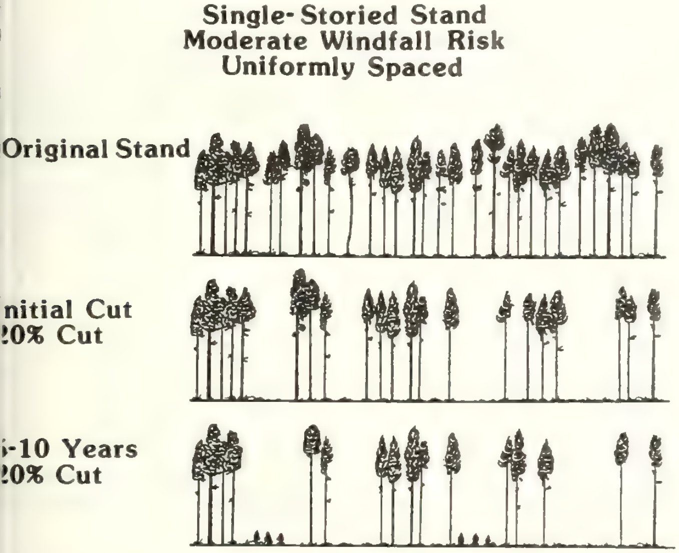
The final entry into these clumpy stands should remove the remaining groups of merchantable trees. The timing of this cut depends upon the cone habit and how the manager decides to regenerate the openings. If it is by natural regeneration and the stand is classified as nonserotinous or intermediate cone habit, the final harvest must be delayed until the trees in the original openings are large enough to provide a seed source.

In these stands, the manager again may choose to remove less than 30% of the basal area and cut over less than one-third of the area at any one time. This will require more entries; but new cuts should not be made until the openings cut the previous entry have regenerated. Furthermore, in stands with nonserotinous or intermediate cone habit, the last groups cannot be cut until there is either an outside seed source or the manager elects to plant these openings.

If windfall risk is moderate and trees are uniformly spaced, the first cut should be limited to a light preparatory cutting that removes about 20% of the basal area on an individual-tree basis (fig. 21). The objective is to open up the stand, but at the same time minimize the windfall risk to the remaining trees. Provision should e made, however, to salvage blowdowns. This type of utting resembles a sanitation cut, in that the lowest igor and poorest risk trees should be removed; but it s important to maintain the general level of the overstory anopy intact. Mixed stands should be handled the same s in low windfall risk situations, except that less basal rea should be removed.

The second entry can be made in about 5 to 10 years fter the first cut. This entry should remove about 20% f the original basal area on an individual-tree basis. Vindfalls that were salvaged after the first cut should e included in the computation of the basal area to be emoved. The objective of this preparatory cut is to ontinue to minimize the risk of blowdown while preparing the stand for the seed cut. Most of the trees narked for removal should come from the smaller crown nd poorer vigor classes; but maintain the general level f the canopy intact. In mixed stands, cut as much of he recommended basal area to be removed in pine as s possible.

It will require about another 5 to 10 years to determine f the stand is windfirm enough to make another entry. his will be the seed cut, and should remove about 20% f the original basal area including any windfalls since he last cutting. The largest and most vigorous dominants nd codominants in mixed stands and pure stands with onserotinous or intermediate cone habit should be eserved as a seed source; but it is more important to listribute the cut over the entire area.



igure 21.—Sequence of entries for a shelterwood in a uniformly-spaced, single-storied lodgepole pine stand in a moderate wind risk situation.

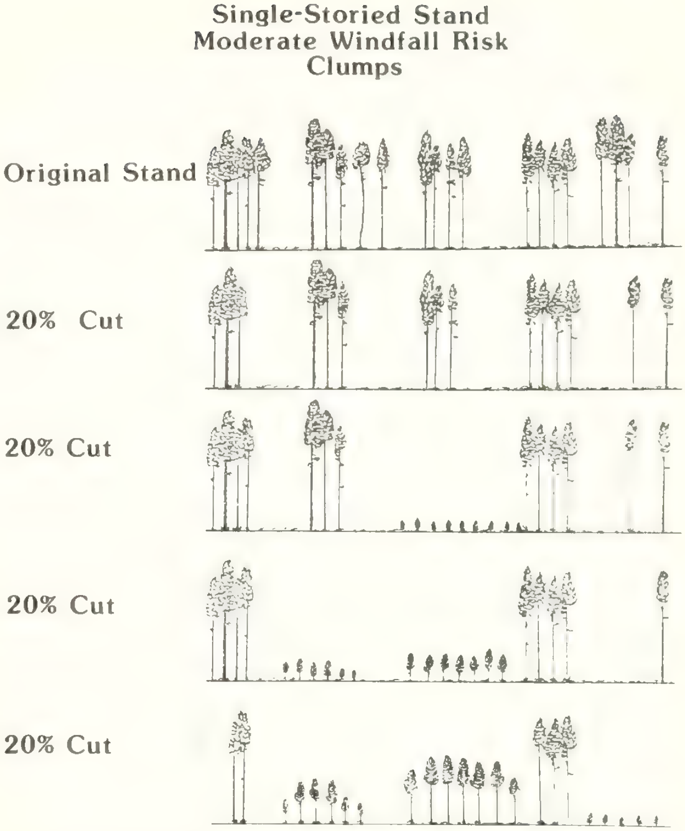


Figure 22.—Sequence of entries with a group shelterwood in an irregularly-spaced, single-storied lodgepole pine stand in a moderate wind risk situation.

The last entry is the final harvest, which should remove the remaining original overstory. It cannot be made until a manageable stand of reproduction has been established. About 40% of the original basal area will be removed in this cut, and if it is too heavy (10,000 fbm or more per acre) to be removed in one harvest without undue damage to the reproduction, the manager must plan on a final harvest in two stages ("stage logging"). The second stage can begin as soon as skidding is finished in the first stage.

The manager also has the option of removing less than 20% of the basal area at any entry and making more entries; but they cannot be made at more frequent intervals.

If windfall risk is moderate and trees are clumpy or irregularly spaced, the first cut should be light, removing about 20% of the basal area in a group shelterwood (fig. 22). Openings should be no larger than one tree height in diameter, and not more than one-fifth of the area should be cut over at any one time. All trees in a clump should be cut or left. In stands with small natural openings—about one tree height in diameter—the openings can be enlarged one tree height by removing clumps of trees to the windward.

Four additional entries into the stand can be made at periodic intervals; but no new entry should be made until the openings cut the previous entry have regenerated. In stands with nonserotinous cones, the last groups to be removed should be retained until the original group openings are large enough to provide a seed source, or plan on planting the openings created by the last cut.

About 20% of the basal area should be removed over about one-fifth of the area at each entry. Group openings should be no larger than one tree height in diameter.

If windfall risk is very high, the choice is limited to removing all the trees or leaving the area uncut. Cleared openings should not be larger than regeneration requirements dictate, and they should be interspersed with uncut areas of at least equal size.

Two-storied stands.—These stands may appear to be two-aged (fig. 23), but can contain more than two age classes. Top story—dominants, codominants, and intermediates—resembles a single-storied stand. The second story is composed of younger trees of smaller diameter—small logs, poles, or saplings—than the top story; but it is always below and clearly distinguishable from the overstory. Trees in the second story are overtopped and may or may not be suppressed.

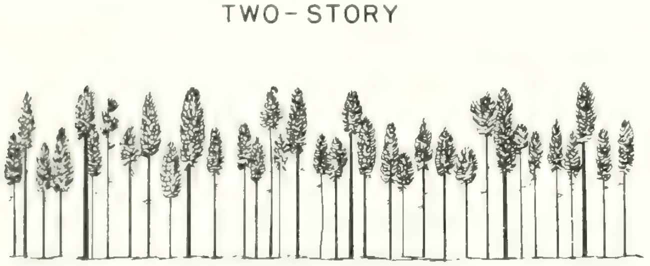


Figure 23.—A two-storied lodgepole pine stand.

If more than two-aged, the overstory usually contains at least two age classes. The younger trees are finer limbed and may be smaller in diameter than the older trees. The second story may also contain more than one age class. Stocking of the overstory may be irregular; but overall stocking is usually uniform. A manageable stand of advanced reproduction is usually absent.

In mixed stands, the overstory is usually pure pine; but occasionally it may be pine with spruce or Douglas-fir. The second story is usually spruce and fir at the higher elevations, and Douglas-fir at the lower elevations. Stocking in mixed stands may vary from uniform to irregular. Mixed stands may have a manageable stand of advanced reproduction of species other than pine.

Recommended cutting treatments are the same as for three-storied stands.

Three-storied stands.—These stands may appear to be three-aged (fig. 24); but they can contain more than three age classes, although stands are seldom broad-aged. The top story resembles a single-storied stand except that there are fewer trees. The second and third stories consist of younger, smaller diameter trees. The second story may be small saw logs or large poles, while the third story is likely to be composed of small poles or saplings. Second and third stories are overtopped, and some trees may be suppressed. Overall stocking is likely to be uniform, but stocking of any story may be irregular. A manageable stand of advanced reproduction is usually absent.

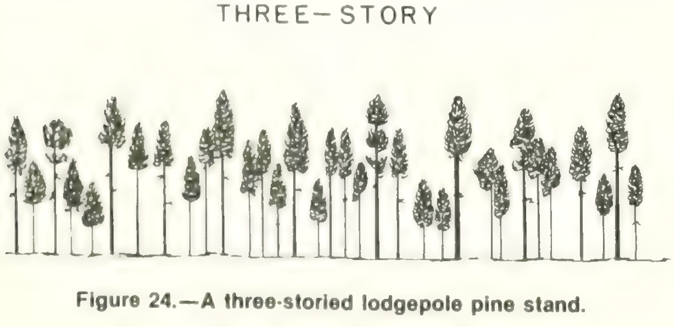


Figure 24.—A three-storied lodgepole pine stand.

In mixed stands, the top story may be either pure pine or a mixture of pine and other species. The second story is usually spruce and subalpine fir at the higher elevations, and Douglas-fir at the lower elevations. The second story occasionally may contain some pine; but it is rarely pure pine. The third story almost always is composed of species other than pine. Stocking in mixed stands can vary from uniform to irregular. Mixed stands often have a manageable stand of advanced reproduction of species other than pine.

Trees in the top story of two- and three-storied stands usually are more windfirm than those in a single-storied stand. Trees in the second and third stories usually are less windfirm than trees in the top story.

If windfall risk is low and trees uniformly spaced, the first cut can remove up to 50% of the basal area in two-storied stands (provided that not more than 50% of the basal area removed comes from the top story), and up to 40% of the basal area from three-storied stands (fig. 25). This cutting is as heavy as the first or seed cut of a two-cut shelterwood; but marking follows the rules for individual-tree selection. Heavier cutting may be possible in three-storied stands; but the appearance of a continuous overstory is not likely to be retained. Trees removed should be in vigor classes C and D as much as possible; but because the top story is likely to be more windfirm, selected dominants and codominants should be left even when they are in vigor classes C and D, if they do not have dead or dying tops. Avoid cutting holes in the canopy larger than one tree height in diameter by distributing the cut over the entire area. Do not remove dominant trees that are protecting other trees to their leeward if these latter trees are to be reserved for the next cut. In a mixed stand, if the top story or, rarely, the first

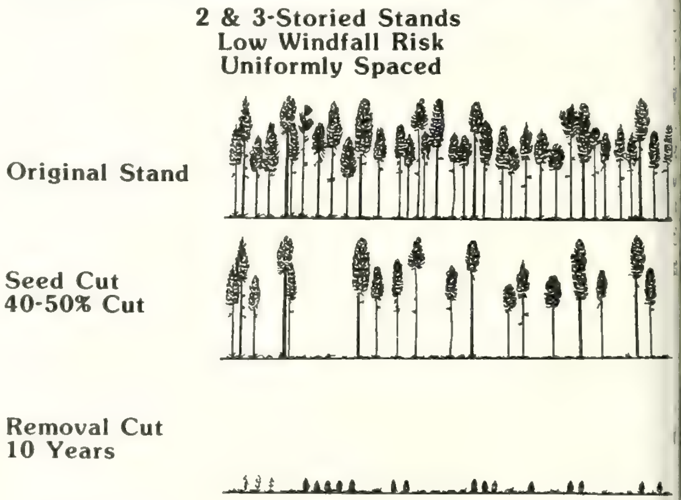


Figure 25.—Sequence of entries with a two-cut shelterwood in a uniformly-spaced, two- or three-storied lodgepole pine stand in a low wind risk situation.

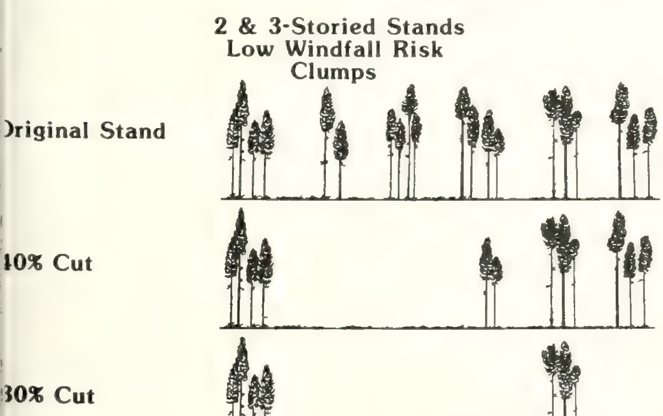
nd second stories are pure pine, handle it as a pure tand. If the top story is of mixed composition, cut as uch of the basal area to be removed in pine as is possile to release the climax species; but do not cut all of e pine if it is needed to maintain the overstory.

The second entry should be the final harvest to remove e remaining original stand and release the reproducon. It cannot be made until the new stand of reproducon is established. If the residual volume is greater than bout 10,000 fbm per acre, the final harvest should be ade in two stages to avoid undue damage to newly stablished reproduction. The second stage can begin as oon as skidding is finished in the first stage.

If there is a manageable stand of advanced reproducon under mixed stands, the first cut can be a simulated helterwood if the volume is not too heavy. Otherwise, e first cut can remove 40% to 50% of the basal area n an individual-tree basis as long as the more windfirm ominants and codominants are left. The timing of the econd cut is not critical from a regeneration standpoint, rovided that a manageable stand of reproduction still xists after the first cut and can be saved.

The manager has other options to choose from, inluding cutting less than the recommended basal area, aking more entries, and spreading the cut out over a nger period of time by delaying the final harvest until e new stand is tall enough to create the appearance f a high forest. This is not recommended where mounin pine beetles and dwarf mistletoe limit the way stands an be handled.

If windfall risk is low and trees grow in clumps or spacg is irregular, in pure or mixed stands with irregular r clumpy stocking that may have resulted from the reakup of single-storied stands, old beetle attacks, or indfall losses, an alternative first cut can remove about 0% of the basal area in a group shelterwood (fig. 26). he group openings can be larger (two or three times ee height) than in single-storied stands; but the area cut over should not exceed about one-third of the total. Openings should be irregular in shape without windcatching indentations in the borders. This kind of cutting is not applicable in pure stands where mountain pine beetle or dwarf mistletoe impose limitations; because the interval between initial cutting and final harvest is likely to be too long to prevent serious mistletoe infection of new reproduction and/or loss of beetle-susceptible trees.



gure 26.—Sequence of entries with a group shelterwood in an irregularly-spaced, two- or three-storied lodgepole pine stand in a low wind risk situation.

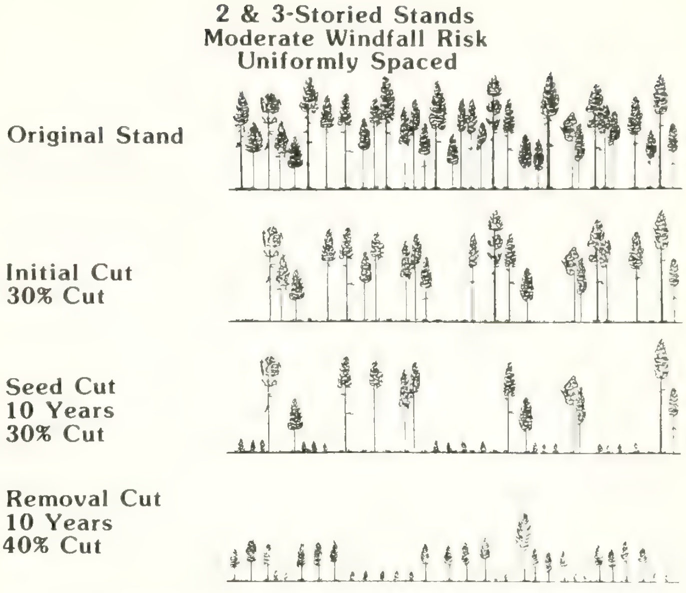


Figure 27.—Sequence of entries with a three-cut shelterwood in a uniformly-spaced, two- or three-storied lodgepole pine stand in a moderate wind risk situation.

Two additional entries can be made in the stand. They should each remove about 30% of the original basal area in group openings up to two to three times tree height; but not more than one-third of the area should be cut over at any one time. If there is not a manageable stand of advanced reproduction, the manager must wait until the first openings are regenerated before cutting the second series. Furthermore, in mixed stands, or pure stands with the nonserotinous or intermediate cone habit, cutting the final groups either must be delayed until there is a seed source or these openings must be planted. If there is a manageable stand of advanced reproduction, the timing between cuts is not critical for regeneration.

The manager has the option in mixed stands of removing less than the recommended basal area and cutting less than the recommended area at any one time. This will require more entries and spread the cut out over a longer period of time.

If windfall risk is moderate and trees are uniformly spaced, the first entry should be a preparatory cut that removes not more than 30% of the basal area on an individual-tree basis (fig. 27). Predominants, and codominants, and intermediates with long live crowns should be removed first. The remaining cut should then come from trees in vigor classes C and D. Maintain the general level of the canopy by not cutting holes larger than one tree height in diameter in the canopy. Provision should be made to salvage blowdowns. Mixed stands should be handled as in low wind risk situations, except that less basal area should be removed.

The second entry should not be made in less than 10 years. This cut should remove about 30% of the original basal area, including the salvage of any windfalls after the first cut. During this seed cut, the best dominants and codominants should be reserved as a seed source in stands with the nonserotinous or intermediate cone habit; but it is important that the cut be distributed over the entire area.

The next entry is the final harvest to remove the remaining merchantable volume and release the new reproduction after it has become established. However, if the residual stand volume is too heavy, the final harvest should be made in two steps.

In mixed stands that contain a manageable stand of reproduction, where the volume per acre is not too heavy, the first cut can be a simulated shelterwood. If the volume is too heavy for a one-step removal, the manager should follow the recommendations for pure stands, because the wind hazard is too great to permit a two-step removal in a stand that has not been previously opened up to develop windfirmness.

If windfall risk is moderate and trees are clumpy or irregularly spaced, the first cut should be a group shelterwood that removes about 25% of the basal area (fig. 28). Openings should be kept small—not more than one or two tree heights in diameter—and not more than one-fourth of the area should be cut over at any one time. All trees in a clump either should be cut or left. Small natural openings can be enlarged one or two tree heights by removing trees in clumps to windward of the opening.

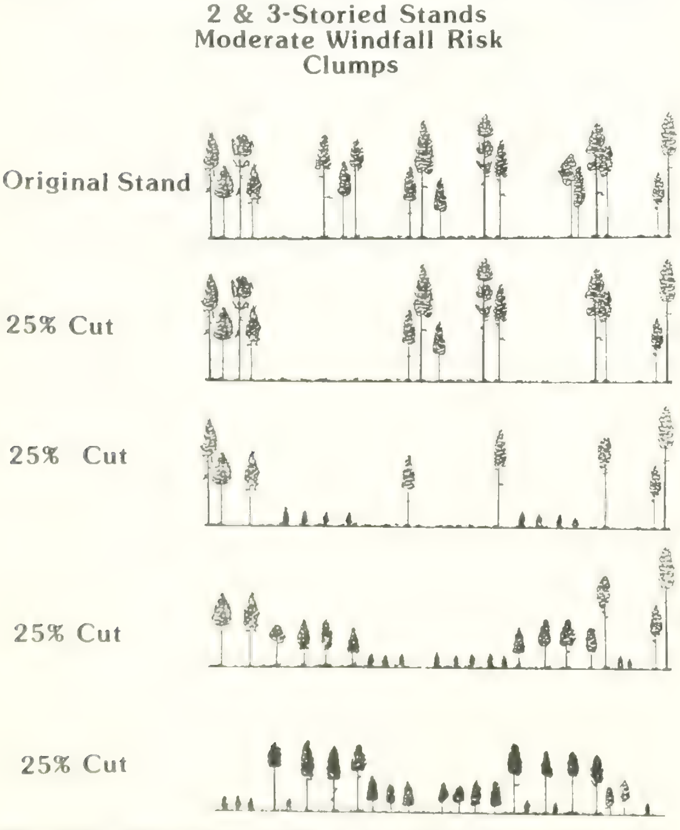


Figure 28.—Sequence of entries with a group shelterwood in an irregularly-spaced, two- or three-storied lodgepole pine stand in a moderate wind risk situation.

Three additional entries should be made. About 25% of the original basal area should be removed on about one-fourth of the area in each entry. The interval between cuts will depend upon the time required to regenerate each series of openings. The manager must either delay the removal of the final groups until a seed source is available or plant the openings.

If windfall risks are very high, the choice usually is limited to removing all the trees or leaving the area uncut. Cleared openings should not be larger than regeneration requirements dictate, and should be interspersed with uncut areas. Not more than one-third of the total area in this windfall risk situation should be cut over at any one time.

Multi-storied stands.—These stands are usually broad-aged (fig. 29) with a wide range in diameters. If stands developed from relatively few individuals following disturbance, the overstory trees are coarse limbed. Fill-in trees are better formed and finer limbed. Vigor of the overstory trees varies from poor to good. In stands that developed from deterioration of single- or two-storied stands, the overstory trees may be no limbier than the fill-in trees. Nearly all of the healthy, faster growing trees are below saw-log size. Stocking may be irregular. A manageable stand of advanced reproduction may be present.

In mixed stands, the overstory may be either (1) pure pine, or (2) a mixture of pine, spruce, and fir at the higher elevations, or pine and Douglas-fir at lower elevations Overstory trees have the same characteristics as pure stands, except that the composition is likely to be other than pine. Stocking in mixed stands is more likely to be irregular. Mixed stands frequently have a manageable stand of advanced reproduction of species other than pine. These are usually the most windfirm stands, even where they have developed from the deterioration of single- and two-storied stands. By the time they have reached their present condition, the remaining overstory trees are likely to be windfirm.

If windfall risk is low, there is considerable flexibility in harvesting these stands. All size classes can be cut with emphasis on either the largest or smallest trees in the stand. The first cut can range from an overwood removal to release the younger growing stock, to a thinning from below to improve the spacing of the more vigorous of the larger trees. Thereafter, cutting can be directed toward either even-aged or uneven-aged management (fig. 30). In mixed stands, the first cu should be a simulated shelterwood that removes the overstory pine to release the climax species. The understory trees should be thinned to improve spacing.

If windfall risk is moderate to high, the safest first cu is an overwood removal with a light thinning from below, to obtain a wider spaced, more open stand that can develop windfirmness. Thereafter, cutting can be directed toward either uneven- or even-aged managemen (fig. 31).

Modification to partial cutting practices imposed by disease and insect problems.—For dwarf mistletoe, cu only in stands where the average mistletoe rating is or less, and remove only the percentage of basal area

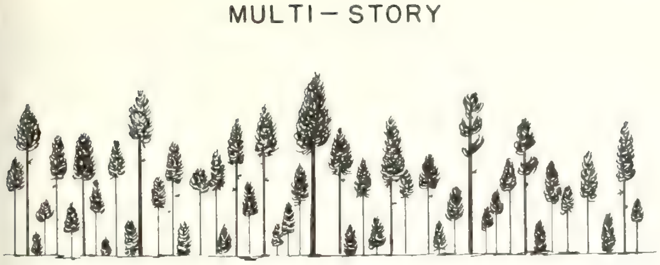


Figure 29.—A multi-storied lodgepole pine stand.

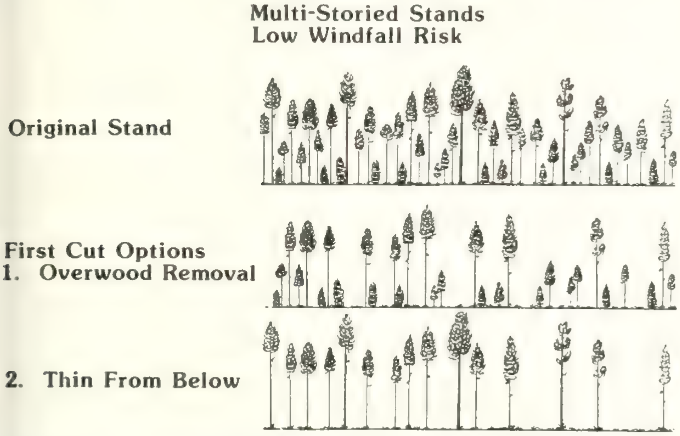


Figure 30.—Sequence of entries in a multistoried lodgepole pine stand in a low to moderate wind risk situation.

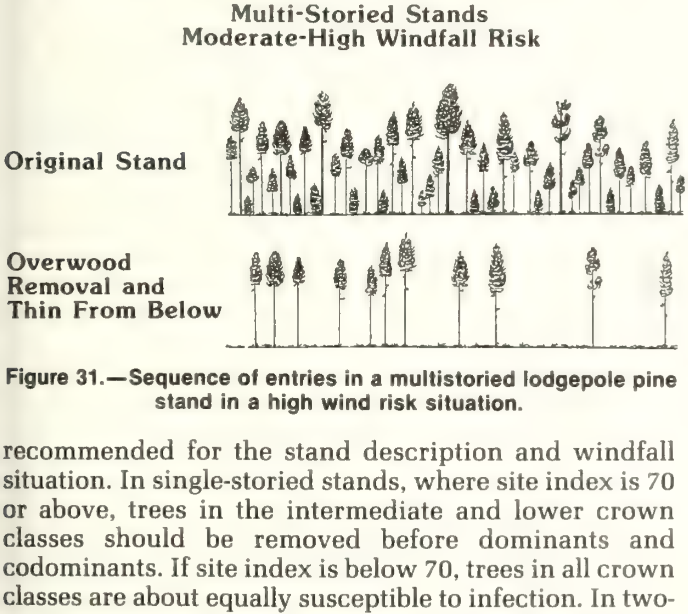


Figure 31.—Sequence of entries in a multistoried lodgepole pine stand in a high wind risk situation.

recommended for the stand description and windfall situation. In single-storied stands, where site index is 70 or above, trees in the intermediate and lower crown classes should be removed before dominants and codominants. If site index is below 70, trees in all crown classes are about equally susceptible to infection. In two- and three-storied stands, as much of the first cut as is possible should come from the second and third stories, because these trees are likely to be more heavily infected than the top story. In single-, two-, and three-storied stands, the final overstory removal can be delayed until the new reproduction is tall enough to provide a forest aspect. To minimize infection of new reproduction, however, time interval should not exceed 30 years after the regeneration cut when the average mistletoe rating is 1, or 20 years when the rating is 2. Provision should be made to sanitize the young stand at the time of final harvest (Hawksworth et al. 1977). In multi-storied stands, the safest procedure is an overwood removal with a cleaning and thinning from below.

In old-growth stands with an average mistletoe rating greater than 2, any partial cutting, thinning, or cleaning is likely to intensify the infection. The safest procedure, therefore, is either to remove all of the trees and start a new stand or to leave the stand uncut. If the manager chooses to make a partial cut for any reason, the initial harvest should be heavy enough to be a regeneration cut. All residual trees must be removed within 10 years after the first cut, and provision made to sanitize the young stand at that time.

For comandra blister rust, cut as many trees with stem cankers and spike-tops as possible in the first cut without removing more than the recommended basal area or cutting large openings in the canopy. Because the rate of spread in mature trees is relatively slow and the disease is not transmitted from pine to pine, leaving a few infected trees is less of a risk than opening up the stand too much.

If mountain pine beetle is present in the stand at an endemic level, or in adjacent stands in sufficient numbers to make successful attacks, and less than the recommended percentage of basal area to be removed in the first cut is in susceptible trees, any attacked tree and all of the most susceptible trees should be removed in the first cut. This will include most of the trees 12 inches d.b.h. and larger, and all trees 10 to 12 inches d.b.h. in vigor classes A and B. Provision should be made to salvage attacked trees, and the second cut should be made within 10 years of the first cut.

If, in these stands, more than the recommended percentage of basal area to be removed in the first cut is in susceptible trees, the manager has three options:

(1) remove all the trees, burn the green culls and unmerchantable portions of trees, and regenerate a new stand; (2) remove the recommended basal area in attacked and susceptible trees and accept the risk of future losses; or (3) leave the stand uncut. If the stand is partially cut or left uncut, some trees from 5 to 12 inches d.b.h. will survive.

If the stand is sustaining an infestation that is building up, and the manager chooses to either partially cut or leave the stand uncut, there is a risk of an outbreak that could destroy most of the stand 5 inches d.b.h. and larger.

Cutting to save the residual.—In shelterwood cutting, protection of the residual stand from logging damage is a primary concern. The residual stand includes merchantable trees left after standard shelterwood and reproduction established after the seed cut in standard shelterwood, and reproduction established after each cut in group shelterwood. Before the final harvest is made with standard shelterwood, and before each entry with group shelterwood, the manager must determine if there is an acceptable stand of reproduction. Furthermore, the stand must be reevaluated after final harvest in standard shelterwood and after each entry with group shelterwood to determine the need for supplemental stocking. The same criteria used to minimize damage and evaluate advanced reproduction with a simulated shelterwood applies here (fig. 32).

Slash disposal and seedbed preparation.—Some treatment of logging slash and unmerchantable material probably will be needed after each cut. Treatment should be confined to concentrations and that needed to reduce visual impact, however, because most equipment now available for slash disposal is not readily adaptable to working in shelterwood cuttings. Furthermore, burning slash will not only cause damage to the residual stand, but may destroy the seed supply in stands with serotinous cones. Skid out as much of the downed sound dead and green cull material as possible for disposal at the landings or at the mill. Treatment in stands should be limited to lopping and scattering, chipping along the roadway, and hand piling and burning to minimize damage. In group shelterwood cutting, if there is not a manageable stand of advanced reproduction, dozers equipped with brush blades can be used to concentrate slash for burning in the openings. Piles should be kept small to reduce the amount of heat generated. Stands with the serotinous cone habit should not be treated until the cones have had time to dry out and open up (Alexander 1974).

On areas to be regenerated, a partial overstory canopy or trees standing around the margins of small openings provide two of the basic elements necessary for regeneration success in stands with the nonserotinous or intermediate cone habit—a seed source within effective seeding distance, and an environment compatible with germination, initial survival, and seedling establishment. In stands with the serotinous cone habit, the seed supply is largely in the cones attached to the slash or scattered on the ground. The manager must make sure that the third element—a suitable seedbed—is provided after the regeneration cut where standard shelterwood cutting is used, and after each cut where group shelterwood is used. Unless at least 40% of the available ground surface is exposed mineral soil after logging and slash disposal, additional seedbed preparation is needed. Until special equipment is developed, seedbed preparation as well as slash disposal will pose problems. The equipment currently available is too large to work well around standing trees. Small dozers or other machines equipped with brush blades will have to be used (Alexander 1974).

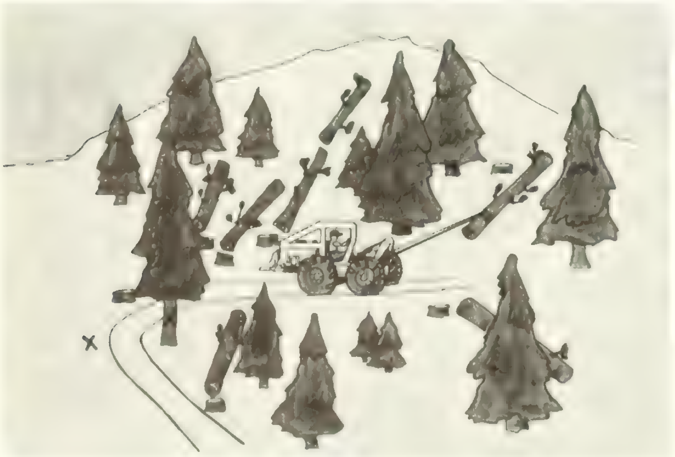


Figure 32.—Schematic drawing of layout of skidroads and felling patterns.

UNEVEN-AGED CUTTING METHODS

Normally, lodgepole pine is best maintained as a vigorous, productive forest under even-aged cutting methods. However, multi- and three-storied stands frequently are uneven- to broad-aged or have diameter distributions more closely associated with uneven-aged stands. Moreover, uneven-aged management may be more compatible or desirable for some management objectives or resource needs. For example, the impact on the forest should be as light as possible in areas of erosive soils, or where management goals include maintenance of continuous high forests.

Uneven-aged management includes cultural treatments, thinnings, and harvesting necessary to maintain continuous high forest cover, provide for regeneration of desirable species, either continuously or at each harvest, and provide for controlled growth and development of trees through the range of size classes needed for sustained yield of forest products. Managed uneven-aged stands are characterized by trees of many sizes and/or ages intermingled singly or in groups. Cutting methods do not produce stands of the same age that are large enough to be recognized as a stand. Forests are subdivided into recognizable units that can be located on the ground on the basis of timber type, site, logging requirements, etc., rather than acreage in stand-age classes. Regulation of young growing stock is accomplished by setting: (1) a residual stocking goal, in terms of basal area or volume, that must be maintained to provide adequate growth and yield, (2) a diameter distribution goal that will provide for regeneration, growth and development of replacement trees, and (3) a maximum tree size goal. In addition, a decision must be made on how to handle small trees.

Procedures described here are for entries into unregulated old-growth lodgepole pine, lodgepole pine-spruce-fir, or lodgepole pine—Douglas-fir stands that are to be converted to managed uneven-aged stands using either individual-tree or group selection cutting. It is not likely that unregulated stands will be brought under management with one entry or even a series of entries. It is more likely that limitations imposed by stand conditions, windfall risk, dwarf mistletoe, and mountain pine beetle susceptibility will result in either over- or undercutting, at least in the first entry.

Individual Tree Selection Cutting

This regeneration cutting method harvests trees in several or all diameter classes on an individual basis. Stands regenerate continuously. The ultimate objective is to provide a stand with trees of different sizes and age classes intermingled on the same site (USDA Forest Service 1983). Choice of trees to be cut depends on their characteristics and relationship to stand structure goals set up to regulate the cut. This cutting method provides maximum flexibility in choosing trees to cut or leave and is appropriate only in uniformly spaced stands with irregular to all-aged structure. However, because of lodgepole pine's silvical characteristics, individual-tree selection cutting is not recommended in pure stands. In mixed lodgepole pine-Engelmann spruce-subalpine fir or mixed lodgepole pine—Douglas-fir stands, individual trees selection can be used; but few pines are likely to become established after initial cutting.

Group Selection Cutting

This regeneration cutting method harvests trees in groups, ranging from a fraction of an acre up to about 2 acres (USDA Forest Service 1983). It is similar to a group shelterwood except in the way the growing stock is regulated. Trees are marked on an individual-tree basis; but emphasis is on group characteristics, which means trees with high potential for future growth are removed along with trees with low growth potential. Loss in flexibility is partly offset by the opportunity to uniformly release established regeneration and reduce future logging damage. When groups are composed of only a few trees, the method can be used together with individual-tree selection cutting in mixed stands. This cutting method is most appropriate in irregular to all-aged mixed or pure lodgepole pine stands that are clumpy or groupy. However, it can be used in uniformly spaced stands with the size, shape, and arrangement of openings based on factors other than the natural stand conditions (Alexander and Edminster 1977a, 1977b).

Stand Structure Goals

Control of Stocking

The first step in applying a selection cut to a lodgepole stand is to determine the residual stocking level to be retained. Because total stand growth for many species under uneven-aged management does not differ greatly over the range of stocking levels likely to be management goals, stocking levels set near the lower limit, where no growth is lost, concentrate increment on fewest stems. This reduces time required to grow individual trees to a specific size, and requires a minimum investment in growing stock (Alexander and Edminster 1977b).

The residual stocking level with the best growth in pure or mixed lodgepole pine stands varies with species composition, management objectives, productivity, diameter distribution, etc. In unregulated old-growth lodgepole pine stands with irregular structure, stocking usually varies from 100 to 200 square feet of basal area per acre in trees in the 4-inch and larger diameter classes. Basal areas above 150 to 160 square feet per acre probably represent overstocking. While no guidelines are available for uneven-aged stands, residual stocking levels of GSL 80 to GSL 160 are suggested for managed even-aged stands, depending on site productivity, number of entries, and other management objectives (Alexander and Edminster 1981). These levels should be useful in estimating initial residual stocking goals in terms of square feet of basal area per acre for that part of the stand that eventually will be regulated under uneven-aged management (Alexander and Edminster 1977b).

While these general recommendation are probably adequate to start with, use of yield tables for even-aged stands in setting stocking goals for uneven-aged stands assumes there is little difference between the growing stock of the two, other than a redistribution of age classes over a smaller area (Bond 1952). This may be true when stands without a manageable understory of advanced growth are harvested by a group selection method. The result is likely to be a series of small, even-aged groups represented in the same proportion as a series of age classes in even-aged management. If advanced growth of smaller trees has become established under a canopy of larger trees, however, a different structure may develop with either individual-tree or group selection systems. Growing space occupied by each age or size class is being shared (Reynolds 1954). Assuming that damage to understory trees resulting from removal of part of the overstory trees can be minimized, advanced growth will successfully establish a series of age classes on some areas. In this situation, more trees of a larger size can be grown per acre than with a balanced even-aged growing stock (Bourne 1951, Meyer et al. 1961). Nevertheless, without better information, the residual stocking goals set for even-aged management are the best criteria available.

Maximum Tree Size

The second item of information needed is the maximum diameter of trees to be left after cutting. In old-growth lodgepole pine stands with irregular spacing, maximum diameter usually varies from 8 to 24 inches d.b.h., depending on stand density, site quality, species composition, etc. Examination of plot inventory information from unmanaged stands with irregular stand structure, suggests that a diameter of 18 inches can be attained within the time period generally considered reasonable under a wide range of site quality and stocking conditions. In the absence of any information on growth rates in uneven-aged stands, or rates of return for specific diameter and stocking classes, an 18-inch maximum diameter seems a reasonable first approximation to set for timber production. Trees of larger diameter with a lower rate of return on investment may be appropriate for multiple-use reasons (Alexander and Edminster 1977b).

Control of Diameter Distribution

Control over distribution of tree diameters also is necessary to regulate yields under uneven-aged management. This most important step is accomplished by establishing the desired number of trees or basal area for each diameter class.

When used with flexibility, the quotient q between number of trees in successive diameter classes is a widely accepted means of calculating diameter distributions in uneven-aged stands (Meyer 1952). Values of q ranging between 1.3 and 2.0 (for 2-inch diameter classes) have been recommended for various situations. The lower the q, the smaller is the difference in number of trees between diameter classes. Stands maintained at a small q have a higher proportion of available growing stock in larger trees, for any residual stocking level, but may require periodic removal of the largest number of small trees in the diameter class where unregulated growing stock crosses the threshold into the proportion of the stand to be regulated (Alexander and Edminster 1977b).

Consider, for example, differences in numbers of small and large trees maintained at a q level of 1.1, 1.3, and 1.5 inches in stands with the same residual basal area (80 square feet) (table 1). At all stocking levels considered appropriate for future management goals, many small trees would have to be cut under lower q levels at the threshold diameter class (in this example the 4-inch class). Fewer larger trees would be retained under higher q levels.

In the absence of any experience, data, or good growth and yield information, the best estimate of numbers of trees to leave by diameter classes is to use the lowest q value that is reasonable in terms of existing markets, stand conditions, and funds available for cultural work. Examination of plot data from a wide range of irregularly stocked old-growth lodgepole pine stands indicates that pretreatment distributions are likely to range between 1.1 and 1.5 for 2-inch classes. As a general recommendation, q levels between 1.3 and 1.5 appear to be reasonable initial goals for the first entry into unmanaged stands, especially mixed stands (Alexander and Edminster 1977b).

How to Determine Residual Stand Structure

Once goals for residual stocking, maximum tree diameter, and q levels have been selected, the specific structure for a stand can be calculated, provided that data are available to construct a stand table (Alexander and Edminster 1977b).

An existing old-growth lodgepole pine stand on the Fraser Experimental Forest in Colorado that was marked and cut as a demonstration is used to illustrate the procedure. The actual inventory data for the stand is shown in columns 1, 2, and 3 of table 2. A residual basal area of 80 square feet per acre in trees 4 inches d.b.h. and larger was chosen, because: (1) it allows maximum reduction (45%) in present basal area consistent with previously developed recommendations for minimizing blowdown after partial cutting (Alexander 1975), and (2) it is the lowest basal area that appears to be a realistic timber management goal in lodgepole pine stands. A maximum tree diameter of 18 inches d.b.h. was chosen, because it also appears to be a realistic goal to be attained in a reasonable period of time. Finally, a q of 1.3 was chosen, because it approximates the q in the natural stand, and does not require removal of many small trees. A lower q may be feasible, but it would require heavy cutting in lower diameter classes.

To determine the residual stand goal, the value of the residual density parameter k corresponding to a basal area of 80 square feet must be calculated. Values needed for this computation with a q of 1.3 are given in column 4 of table 3. The value of k is computed as

$$k = \frac{80.0}{1.09780 - 0.01678} = 74.0042$$

where 80.0 is the desired basal area per acre, 1.09780 is the table value for the desired maximum tree diameter class of 18 inches, and 0.01678 is the table value for the 2-inch class. Note that the value for the 2-inch class is subtracted from the 18-inch class value, because trees smaller than the 4-inch class are not considered in the management guidelines. Desired residual number of trees in each diameter class (columns 4 of table 2) can be directly calculated by multiplying the proper diameter class values given in column 4 of table 4 by the value of k. The desired residual basal area in each diameter class (column 5 of table 2) can be calculated by multiplying the residual number of trees in each diameter class by the tree basal area.

Table 1.—Residual stand structures for 80 square feet of basal area and maximum tree diameter of 18 inches d.b.h. for various q values.

Diameter class (inches)	q = 1.1		q = 1.3		q = 1.5	
	No. of trees	BA (ft.^{2})	No. of trees	BA (ft.^{2})	No. of trees	BA (ft.^{2})
4	20.86	2.03	42.85	3.74	75.28	6.57
6	18.94	3.72	33.74	6.62	50.16	9.84
8	17.23	6.02	25.91	9.04	33.90	11.83
10	14.98	8.17	19.98	10.90	22.31	12.17
12	14.23	11.18	15.37	12.07	14.90	11.70
14	12.84	13.73	11.81	12.66	9.92	10.61
16	11.77	16.43	9.08	12.68	6.61	9.22
18	10.70	18.91	6.98	12.33	4.41	8.07
Total	121.55	80.19	165.72	80.05	217.49	80.01

Table 2.—Actual stand conditions and management goals for a lodgepole pine stand. All data on a per acre basis—stand goals q = 1.3, residual basal area 80 square feet, maximum diameter of 18 inches d.b.h.

Diameter class (inches) (1)	Actual stand		Residual Stand Goal		Final Stand		Cut	
	Trees (2)	BA (ft.^{2}) (3)	Trees (4)	BA (ft.^{2}) (5)	Trees (6)	BA (ft.^{2}) (7)	Trees (8)	BA (ft.^{2}) (9)
4	158	13.79	58.16	5.08	58	5.06	100	8.73
5	74	10.09	44.74	6.10	45	6.14	29	3.95
6	55	10.80	34.41	6.76	34	6.67	21	4.13
7	46	12.30	26.47	7.08	26	6.95	20	5.35
8	26	9.08	20.36	7.11	20	6.98	6	2.10
9	29	12.81	15.66	6.92	16	7.07	13	5.74
10	19	10.36	12.05	6.57	12	6.55	7	3.81
11	19	12.54	9.27	6.12	9	5.94	11	7.26
12	22	17.28	7.13	5.60	8	6.28	14	11.00
13	15	13.83	5.48	5.06	7	6.45	8	7.38
14	7	7.48	4.22	4.51	5	5.34	2	2.14
15	6	7.36	3.22	3.95	5	6.14	1	1.22
16	4	5.58	2.50	3.49	2	2.79	2	2.79
17	1	1.58	1.92	3.03	1	1.58	0	0
18	0	0	1.48	2.61	0	0	0	0
Total	481	144.88	247.07	79.99	248	79.94	233	64.94

Table 3.—Values needed to compute k for different q ratios and diameter ranges using basal area as the density measure (Alexander and Edminster 1977b).

2-inch diameter classes (1)	q ratio									
	1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)	1.6 (7)	1.7 (8)	1.8 (9)	1.9 (10)	2.0 (11)
2	0.01983	0.01818	0.01678	0.01558	0.01454	0.01364	0.01283	0.01212	0.01148	0.01091
4	.09196	.07878	.06842	.06011	.05333	.04772	.04303	.03905	.03566	.03273
6	.23948	.19241	.15779	.13166	.11151	.09566	.08300	.07272	.06428	05727
8	.47790	.36075	.28001	.22253	.18046	.14893	.12479	.10597	.09107	.07909
10	.81656	.57994	.42691	.32394	25228	.20094	.16320	.13484	.11310	09613
12	1.25990	84297	58963	42825	32124	24775	19574	15793	12979	10840
14	1.80848	1.14132	.75999	.52966	.38380	.28758	.22179	.17539	.14175	.11675
16	2.45985	1.46605	.93116	.62428	.43828	.32009	.24181	.18806	.14997	12221
18	3.20930	1.80854	1.09780	.70981	.48425	.34580	.25671	.19697	.15545	12566
20	4.05043	2.16089	1.25606	.78523	52209	.36565	.26753	.20308	.15901	.12779
22	4.97568	2.51618	1.40336	.85042	55251	.38065	.27524	.20719	16127	12908
24	5.97669	2.86853	1.53820	.90583	.57682	.39181	.28063	.20991	16269	.12985
26	7.04470	3.21314	1.65994	.95229	.59576	.40000	.28435	.21168	16357	13030
28	8.17072	3.54619	1.76854	.99077	.61041	.40593	.28689	.21282	16410	13056
30	9.34585	3.86479	1.86444	1.02232	.62162	.41019	.28861	.21354	16443	13071
32	10.56133	4.16688	1.94837	1.04797	.63012	.41322	.28975	.21400	.16462	13079
34	11.80875	4.45107	2.02126	1.06864	.63652	.41536	.29052	.21429	16474	.13084
36	13.08011	4.71658	2.08412	1.08520	.64131	.41685	.29102	.21447	.16480	13087

Table 4.—Values needed to compute desired number of residual trees for different q ratios (Alexander and Edminster 1977b).

2-inch diameter classes D_i (1)	q ratio									
	1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)	1.6 (7)	1.7 (8)	1.8 (9)	1.9 (10)	2.0 (11)
2	0.909091	0.833333	0.769231	0.714286	0.666667	0.625000	0.588235	0.555556	0.526316	0.500000
4	826446	694444	591716	510204	444444	390625	346021	308642	277008	250000
6	.751315	.578704	.455166	.364431	296296	.244141	.203542	.171468	.145794	.125000
8	.683013	.482253	.350128	.260308	.197531	152588	119730	095260	076734	062500
10	.620921	.401878	.269329	185934	.131687	.095367	.070430	052922	040386	031250
12	.564474	.334898	207176	132810	.087791	059605	041429	029401	.021256	.015625
14	.513158	.279082	.159366	.094865	.058528	037253	024370	016334	.011187	.007813
16	.466507	.232568	.122589	.067760	.039018	023283	.014335	.009074	.005888	003906
18	.424098	.193807	.094300	048400	026012	014552	008433	.005041	003099	.001953
20	.385543	.161506	.072538	.034572	.017342	.009095	.004960	002801	.001631	000977
22	.350494	.134588	055799	.024694	.011561	005684	.002918	.001556	000858	.000488
24	.318631	.112157	.042922	.017639	007707	.003553	.001716	.000864	.000452	.000244
26	.289664	.093464	.033017	.012599	.005138	.002220	.001010	.000480	000238	.000122
28	.263331	.077887	.025398	.008999	.003425	.001388	.000594	.000267	000125	000061
30	.239392	.064905	.019537	.006428	.002284	000867	.000349	000148	.000066	000031
32	.217629	.054088	.015028	.004591	.001522	.000542	.000206	.000082	.000035	.000015
34	.197845	.045073	.011560	.003280	.001015	.000339	.000121	.000046	.000018	.000008
36	.179859	.037561	.008892	.002343	.000677	000212	.000071	.000025	000010	000004

Comparing actual and desired diameter distributions shows where deficits and surpluses occur (fig. 33). To bring this stand under management, the number of trees should be allowed to increase in the diameter classes that are below the idealized stocking curve, with cutting limited to those diameter classes with surplus trees. As a guide, enough trees should be left above the curve in surplus diameter classes to balance the deficit in trees in diameter classes below the curve. In this example, all surplus trees were cut in the 4- to 11-inch diameter classes, while 1 to 2 surplus trees were left in the 12- to 15-inch classes to make up for deficits in the 16- to 18-inch classes. The final stand structure is shown in fig. 34 and columns 6 and 7 of table 2. Columns 8 and 9 show the trees and basal area removed (fig. 35).

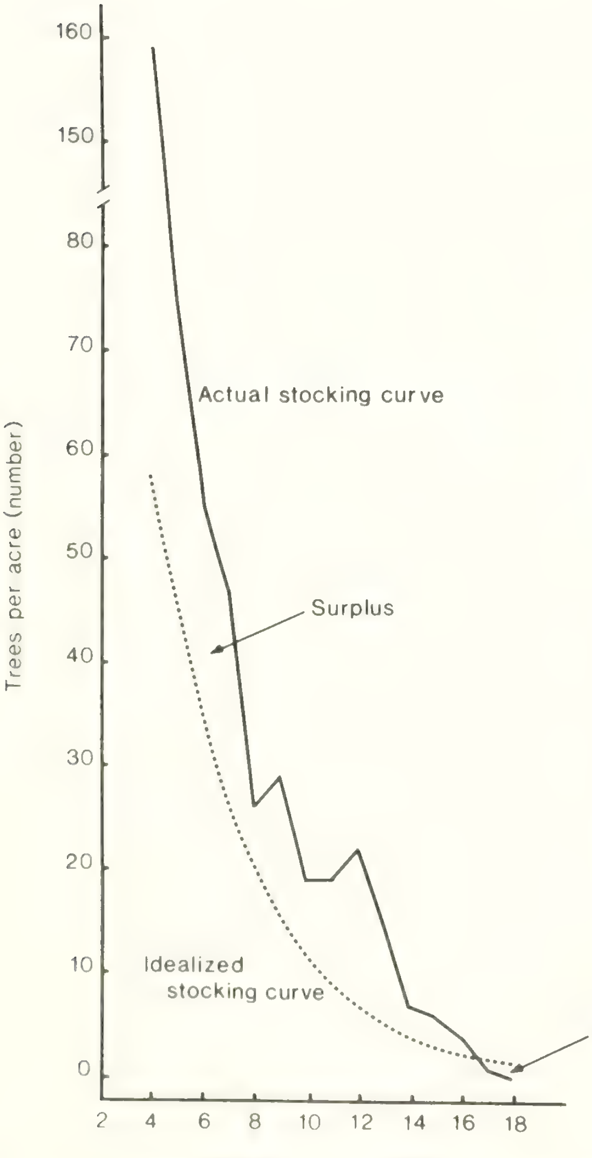


Figure 33.—Actual stocking curve from data collected on the Fraser Experimental Forest and the idealized stocking curve based on stand structure goals.

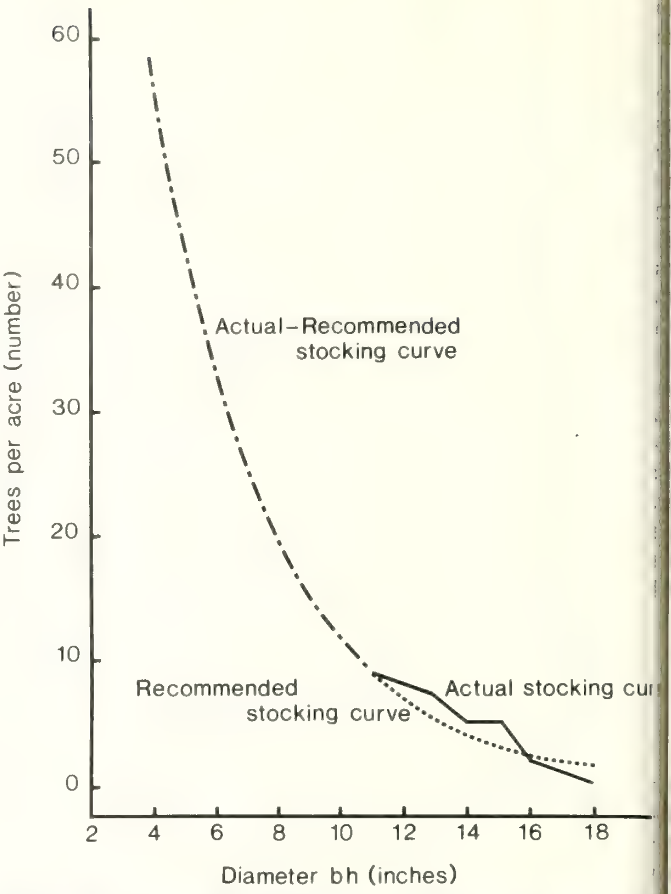


Figure 34.—Actual stocking curve and recommended stockin curve based on stand structure goals and actual stand structur

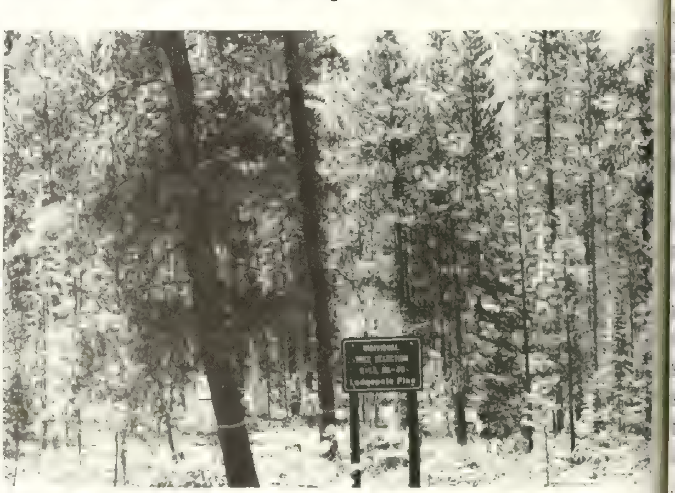


Figure 35.—Individual-tree selection cutting in a multistori lodgepole pine stand, on the Fraser Experimental Forest bas on figure 34.

How to Handle Small Trees

The threshold diameter class also must be determine Calculations often are made down to the 4-inch diamete class by 2-inch classes, because often there are sma trees, especially in mixed stands that are below minimu merchantable diameter. They compete with larger ste for growing space. More important, these trees provid ngrowth into merchantable size classes needed to prac-ce selection silviculture.

Although small trees should not be ignored in inven-ory and record keeping, it may be neither desirable nor ossible to regulate the number of them. In lodgepole ine forests in the central Rocky Mountains, minimum nerchantable diameter is usually 7 to 8 inches. Regula-ion of the number of trees below this size requires an nvestment in silvicultural work that may not be recap-ured under current market conditions. However, if trees elow minimum merchantable size are left unregulated, utting must always be heavy in the threshold diameter lasses to bring ingrowth trees down to the desired umber. It also means that more growing space is re-uired for small trees than called for by the idealized tand structure. Moreover, the higher the threshold liameter class, the greater is the proportion of the stand hat is unregulated. More growing space is occupied by rees of low value that will be cut as soon as they cross he threshold diameter (Alexander and Edminster 977b).

Marking Trees

After residual stocking goals have been calculated and a decision has been made on how to handle small trees, he stand must be marked. Marking is difficult, because he marker must designate cut or leave trees, usually with one pass through the stand, based on limited inventory lata. At the same time, the marker must apply good silviculture and be aware of economic limitations. As a general rule, good silvicultural prescriptions are more mportant than strict adherence to structural goals, especially in unregulated stands being cut for the first ime. However, marking without a structural goal—or prescribing structural goals that cannot be attained or applied—defeats the objective of regulation.

Because marking for individual-tree selection cutting s more complex than for other systems, some formal control procedure is necessary. Often, only an estimate of the initial desired residual diameter distribution is needed. With these estimates, basal areas and number of trees to be removed per acre by diameter classes can be determined. Control is maintained by a process of suc-cessive checks of residual versus the goal. For example, he markers should systematically make prism estimates of the residual stand after marking, recording trees by 2- or 4-inch classes on a standard cumulative tally sheet. Periodically, they should convert the prism tally to trees per acre, and compare their average prism estimate to he structural goal. Markers must then adjust to any serious deviation from the structural goal, such as too heavy marking in some diameter classes and too light n others. Their next check will determine if progress s being made or if further changes are needed. By this process, the average residual stand should come fairly close to the structural goal (Alexander and Edminster 1977b).

Marking under group selection cutting is less complex han under individual-tree selection; but control over the diameter distribution also is necessary. The objective is to create a series of openings with each opening containing a given diameter class.

Recommendations for Selection Cutting

These are based on experience, windfall risk, and dwarf mistletoe and mountain pine beetle susceptibility. Selection cutting methods are appropriate for three- and multi-storied pure or mixed stands with irregular or uneven-age stand structure. Individual-tree selection should be confined to mixed stands with uniform spacing. Group selection can be used in stands with either clumpy-groupy spacing or uniform spacing. Selection cutting methods are not appropriate in high wind risk situations, in stands sustaining a mountain pine beetle attack, or in stands where enough beetles are present within the stand or adjacent stands to make fatal attacks, or in stands where the dwarf mistletoe rating is 3 or more.

Stand Structure Goals, Cutting Treatments, and Reentry Schedules

In low wind risk situations, not more than 30% to 40% of the stand basal area should be removed. With individual tree selection, the cut should be distributed over the entire area. With group selection, not more than one-third of area should be cut. If the stand is clumpy, the size of opening should be determined by the size of the clump. If the stand is uniformly spaced, the size of the opening should not exceed two times tree height. In above average wind risk situations, not more than 20% to 30% of the stand basal area is removed. Distribute the cut over the entire area with individual-tree selection. Not more than one-fourth of the area should be cut with group selection. Keep the openings small. If the stand is clumpy, the opening should be no larger than the size of the clump. If the stand is uniformly spaced, openings should not exceed one times tree height.

Maximum tree diameter should not exceed that attained in the unmanaged stand. The diameter distribution should be set at a "q" value that most closely approximates the natural "q" value of the stand. However, remember that low q values require cutting a larger number of trees at the threshold diameter class and high q values retain few larger trees. The threshold value should be set at the smallest diameter class practical. All trees below the threshold diameter class are unregulated. Some diameter classes will have a surplus of trees and some will have a deficit. Surpluses and deficits must be balanced if the residual basal area is to be maintained.

Subsequent entries should be made at 10- to 30-year intervals. While it would be desirable to enter the stand at 10-year intervals, it is not likely that this will be possible in most instances. Some diameter classes will not be completely represented; therefore, volumes available for cutting may not warrant a 10-year reentry until a controlled diameter distribution is attained.

Protecting the Residual Stand

Protection of the residual stand is critical with individual-tree selection cutting because of frequent entries into the stand once a controlled diameter distribution is attained. Damage can result from felling, skidding, and slash disposal.

Felling damage can be reduced by using group selection and dropping trees in the openings, or marking a small clump of trees where felling one large tree will damage several adjacent trees. Procedures outlined for protecting the residual and disposing of slash for shelterwood cutting should be followed here.

COST OF SALE ADMINISTRATION AND LOGGING

Costs are important in harvesting lodgepole pine stands, because values have been low to moderate, and logging is difficult on steep terrain. One of the most important factors affecting the administrative cost of selling timber is the number of entries needed for harvesting. Clearcutting and simulated shelterwood require only one entry. Standard shelterwood requires two to three entries, while group shelterwood, individual-tree and group selection require from three to six entries, depending upon cutting cycles. In managed stands, even-aged systems require a minimum of two additional entries for thinnings; but the number of entries under uneven-aged systems would not change.

Costs of sale layout, marking, and sale contract administration are lower for clearcutting, simulated and group shelterwood, group selection (when groups are near the maximum size), and the final cut of standard shelterwood than for individual tree selection, and the intermediate, preparatory, and seed cuts of standard shelterwood. Costs are reduced, because only cutting boundaries are marked, and no time is spent marking trees to cut or leave. Sale administration is easier, because there are no residual trees to protect and no opportunity to cut unmarked trees. However, reproduction must be protected at the time of final cut under any shelterwood system. Costs for selection methods are further increased, because highly skilled individuals are required to recognize, mark, and protect trees that needed to be left to obtain the regulated distribution of diameter classes.

Timber harvesting usually requires road construction. Clearcutting is the most economical method in terms of volume removed per unit of road, while individual-tree selection is the most expensive. Development of a transportation system to manage forests is a costly front-end investment that will require funding in addition to the value of stumpage at the time of first entry. Once the transportation system has been constructed, road costs should be independent of cutting method.

In addition to producing maximum volume per acre in one operation, clearcutting permits the greatest flexibility in selection of logging equipment and minimum concern for protection of residual trees. The first entry of a standard shelterwood is intermediate in volume production per acre, requires moderate concern for the residual stand, and places some constraints on selecti
of equipment. The final cut of a standard shelterwo
or simulated shelterwood has the advantages of clea
cutting, except for the need to protect the new stan
Individual-tree selection requires maximum concern f
the residual stand. Group selection and group shelte
wood require slightly less if the size of the opening
near maximum. Under uneven-aged and group shelte
wood cutting methods, volumes per entry are interme
ate, size-class diversity of products harvested is ma
imum, and a choice of logging equipment is restrict
to smaller or specialized machines.

MULTIPLE-USE SILVICULTURE

POTENTIAL TIMBER YIELDS

Highest potential timber yields can be realized und
a clearcutting or a two-cut shelterwood option, provide
that the final harvest with a shelterwood is made with
5 years after regeneration is established. Comparab
growth rates can be achieved with group shelterwo
and group selection only if the openings are near t
maximum size (2 acres). Total yields will be less und
a three-cut shelterwood. Under simulated shelterwoo
yield increases resulting from reduction in rotati
length will be offset by the slower growth of tolera
species in the replacement stand. Yields will be co
siderably less under individual-tree and group selecti
in situations where lodgepole pine is difficult to mai
tain and very small openings are cut (Alexander et
1983).

SOIL WATER RESOURCES

Water Yield

In high elevation lodgepole pine forests, the propo
tion of water yielded to precipitation is high because
the cold climate, short growing season, and accumu
tion of overwinter snowpack. Approximately 90% of t
water available for streamflow comes from snowme
The most efficient timber harvest pattern for increasi
water yield (2 + inches) in old-growth forests is to clea
cut about 30% to 40% of a drainage in small, irregula
shaped patches about five to eight times tree height
diameter (3 to 5 acres), interspersed with uncut patch
of about the same size and shape (fig. 36) (Leaf 1975; Le
and Alexander 1975; Troendle 1982, 1983a, 1983
Troendle and Leaf 1981). With this pattern, wind mov
ment across the canopy is changed so that more sno
accumulates in the openings than under adjacent stan

Total snowfall in the drainage may or may not be i
creased by cutting, depending upon aspect (Hoover a
Leaf 1967, Troendle and Meiman 1984); but melt occu
earlier and at an increased rate in the openings, cau
ing the rising limb of the hydrograph to occur earli
than timber harvest. Most of the increase in flow com
during the period before the peak, which may
somewhat higher; but recession flows are about the san
as before harvest.

Increase in streamflow is not likely to significantly minish for 20 to 30 years, and treatment effect will not sappear until the new stand in the openings is tall ough to change the snow accumulation pattern. At that ne, a number of alternatives can be considered. (1) cut the original openings. The remaining area would retained as continuous high forest; trees would be rvested periodically on an individual-tree basis. timately, the reserve stand would approach an all-aged ructure with the overstory canopy remaining at about e same height, although the original overstory could t be maintained indefinitely. (2) Make a light cut stributed over the entire watershed, removing about 0% to 30% of the basal area on an individual-tree basis in small groups. The objective would be to open up e stand enough to develop windfirmness, and salvage w-vigor and poor-risk trees. Openings five to eight mes tree height can then be cut on about one-third of e area. The remaining two-thirds of the area would be tained as permanent high forest, with trees periodically moved on an individual-tree basis or in small groups.) Another alternative that would integrate water and mber production would be to harvest all of the old-owth in a cutting block in a series of cuts spread over 0 to 120 years. Each cutting block would contain at ast 300 acres, subdivided into circular or irregular-aped units approximately 2 acres in size or four to five mes (in diameter) the height of the general canopy level. t periodic intervals, some of these units, distributed ver the cutting block, would be harvested and the open-gs would be regenerated. The interval between cuttings ould vary from as often as every 10 years to as infre-uently as every 30 to 40 years. The percentage of units ut at each interval would be determined by cutting ycle/rotation age × 100. At the end of one rotation, each utting block would be composed of groups of trees in everal age classes ranging from reproduction to trees eady for harvest. The tallest trees would be somewhat horter than the original overstory; but any adverse ef-ect on snow deposition should be minimized by keep-g the openings small and widely spaced (Alexander 974).

igure 36.—Three-acre openings cut to increase streamflow, south-slope lodgepole pine, on the Fraser Experimental Forest.

Cutting openings larger than 5 acres may be less efficient in increasing streamflow because as opening size increases, wind can scour deposited snow causing it to evaporate into the air or blow into adjacent stands where recharge requirements and evapotranspiration are greater. However, these larger openings can be managed to minimize wind scour and maintain snowpack on the site. By leaving residual stems standing and moderately heavy slash in place to provide roughness to hold snow, 20% to 30% more water can be retained in the snowpack than in the uncut forest even in relatively large openings (Troendle and Meiman 1984).

Group selection and group shelterwood cutting can be nearly as favorable for water production as patch clearcutting, if openings are near the maximum size of 2 acres. Increase in water available for streamflow under individual-tree selection will be less than cutting small openings but still significantly higher than in the uncut forest. Canopy reduction by removing trees on an individual basis results in less interception of snow and subsequent evaporation from the canopy. This combined with any other reduction in consumptive use (ET) can result in greater streamflow (Troendle and Meiman 1984).

Standard shelterwood results in increases similar to individual-tree selection as long as an overstory remains. After final harvest under any standard shelterwood alternative, water available for streamflow will increase to the level obtained under patch clearcutting, provided that the area cut is similar in size and arrangement to openings recommended for patch clearcutting. The interval of increased water yield will be proportional to time required for the replacement stand to grow tall enough to modify wind movement across the canopy.

Soil Erosion and Water Quality

Soil and site conditions are not the same in all lodgepole pine forests; but the careful location, construction, and maintenance of skid and haul roads associated with any silvicultural system should not cause a lasting increase in sedimentation. For example, on the Fool Creek drainage in central Colorado, where about 12 miles of main and secondary roads were constructed to remove timber in alternate clearcut strip from about one-third of the drainage, annual sediment yields during road construction and logging were only about 200 pounds per acre (Leaf 1970), and decreased rapidly after logging, despite a persistent increase in runoff. Annual sediment yields after logging have averaged about 43 pounds per acre, compared to 11 to 31 pounds from undisturbed watersheds (Leaf 1975).

Nutrient Losses and Stream Water Temperature Changes

Removal of logs in timber harvest represents a small and temporary net loss of nutrients, because only a minor proportion of the nutrients taken up by a tree is stored in the bole. Clearcutting results in a greater immediate loss than individual-tree selection; but over a similar time frame, the losses would balance out because of more frequent cuts under the selection system. Furthermore, nutrients lost after clearcutting should be replaced in 10 to 20 years through natural cycling as regeneration becomes established.

Comparison of streamflow from logged and unlogged subalpine watersheds in central Colorado provided some indication of effect on chemical water quality. Ten years after clearcutting, cation concentration during a 10-week period was 1.8 ppm greater and cation outflow 5.2 pounds per acre per year greater on the logged watershed (Stottlemeyer and Ralston 1968).

Increases in stream temperature can be avoided, even with clearcutting, by retaining a border of trees along stream channels. Actually, clearcutting to the stream channel and subsequent warming of the water may be advantageous where streams are small and too cold to support adequate food supplies for fish.

WILDLIFE AND RANGE RESOURCES

Game Habitat

Biotic diversity is generally low in old-growth lodgepole pine stands; but these forests provide habitat for a variety of game. Clearcutting, group shelterwood, and group selection provide the largest increases in quantity and quality of forage for big game; but use often is limited by the amount of cover available for hiding, resting, and ruminating. Furthermore, game populations are not directly related to forage availability on summer ranges, because carrying capacity of winter ranges limits the number of animals. Mature unlogged lodgepole pine stands in Colorado produce enough forage to support more mule deer than are presently estimated to occupy summer ranges (Regelin et al. 1974).

Dispersed openings 2 to 20 acres in size are used more by deer and elk than smaller or larger openings or uncut timber (Regelin and Wallmo 1978, Wallmo 1969, Wallmo et al. 1972). Small openings provide little diversity, and overly large openings (more than 40 acres) radically alter in habitat, especially if they are coupled with extensive site preparation and tree planting. As trees grow to seedling and sapling size, forage production in cleared areas diminished (Basile and Jensen 1971, Wallmo et al. 1972); but cover increases until it reaches maximum in mature stands. Because natural succession is likely to replace the more palatable forage species with tree reproduction in 15 to 20 years (Regelin and Wallmo 1978), a more desirable alternative would be to cut new openings periodically while allowing the older cuttings to regenerate. That would provide a constant source of palatable forage and the edge effect desired. The openings created should be widely spaced, with stands between openings maintained as high forest.

One alternative that would integrate wildlife habitat improvement with timber production would be to cut about one-sixth of a cutting block every 20 years in openings about four to five times tree height. Each working circle would be subdivided into a number of cutting blocks (of at least 300 acres) so that not all periodic cu would be made in a single year on a working circl Such periodic cutting would provide a good combin tion of numbers and species of palatable forage plan and the edge effect desired, while creating a several-age forest of even-aged groups (Alexander 1974).

Observations on the Medicine Bow National Forest Wyoming indicate that both natural and cleared ope ings in lodgepole pine forests are heavily used by elk f grazing and calving. The size of opening does not appe to be critical; but openings interspersed with standi timber that can be used for ruminating, resting, a hiding are preferred. Because openings cut in the cano are not likely to retain a high proportion of palatab forage species for long periods of time, new openin should be cut while allowing the older ones to regenera (Alexander 1974).

Standard shelterwood cutting provides less forage f big game than cutting methods that create openings; a the reduction is in proportion to the density of t overstory and length of time it is retained. Shelterwo cutting also provides less cover than an uncut fore Individual-tree selection provides forage and cover co parable to uncut forests, thus maintaining one type habitat at the expense of creating diversity.

Game animals other than deer or elk also are infl enced by the way forests are managed. For example, wi the decrease in wildfires, some reduction in stand de sity of logging may be necessary to create or maintai drumming grounds for male blue grouse. Standa shelterwood, group shelterwood, or group selection cu ting that opens up the stand enough to allow regener tion to establish in thickets provides desirable cove Small, dispersed clearcuts (5 to 10 acres) also a favorable if thickets of new reproduction become esta lished (Martinka 1972).

Nongame Habitat

Little information is available on the relationship cutting methods in lodgepole pine forests to specifi nongame habitat requirements; but it is possible estimate probable effects. Clearcutting, group shelte wood, and group selection that create small, disperse openings provide a wide range of habitats attractive some birds and small mammals by increasing the amou of nontree vegetation—at least initially—and length edge between dissimilar vegetation types. On the Fo Creek watershed, for example, where 40% of the timb was cleared in alternate strips one to six chains wid many species of birds feed in openings and nest in tre along the edge. In contrast, only woodpeckers and sa suckers have been observed in adjacent uncut stand (Myers and Morris 1975).

However, Scott et al. (1982) compared numbers an species of nongame birds on two 100-acre subdrainag on Deadhorse Creek, in the Fraser Experimental Fores One-third of one subdrainage was clearcut in 3-acr patches; the other was left uncut. They found that tot numbers of birds did not significantly change with cu ting. However, there was a small postharvest decline i e “foliage nesting” and “picker” and “gleaner” feeding uilds. There were no significant changes in small mam- al populations after timber harvest. Lodgepole pine rests commonly occur as a long-lived seral on spruce- r habitat types. Clearcutting can maintain lodgepole ne on these sites, thereby maintaining a diversity of over types that is desirable for a variety of nongame ildlife.

Standard shelterwood cutting provides a variety of abitats attractive to species that forage in stands with idely spaced trees, but not to those that require closed rests or fully open plant communities. Under this ethod, trees are still available for nesting, denning, and eding until the final harvest, when consideration ould be given to retaining some of the snags and live ees with cavities. To insure future cavities, Scott et al. 978) recommended leaving all broken-top snags greater an 8 inches d.b.h. and live trees with broken tops or ars.

Harvesting old-growth timber can be devastating to pecies that nest or den in snags and in cavities of live ees, feed largely on tree seeds, or require solitary abitats normally associated with large areas of old-rowth. Most nongame species have a minimum habitat ze below which they can not exist. Small patches of arying ages and structure and all-aged stands may educe the number of species (Alexander et al. 1983). ndividual-tree selection provides the least horizontal iversity, and favors species attracted to uncut forests r that require vertical diversity. However, snags and live ee cavities can be retained under any silvicultural ystem.

Livestock Grazing

Understory vegetation in lodgepole pine forests is otentially important as forage for big game and live- tock; but production varies widely. In dense stands, here is little or no understory vegetation. As the over- tory decreases, forage production increases, reaching aximum in recently clearcut openings or burns. Forage roduction, changes in species composition, and alatability vary considerably, depending upon the plant ommunity and successional stage. The increase in orage production in openings usually persists for about 0 to 20 years before competition from tree reproduc- on begins to reduce understory vigor and composition. t can be maintained only by frequent thinnings and in- ermediate cuts that keep growing stock levels low (Alex- nder et al. 1983).

ECREATION AND ESTHETICS

Lodgepole pine forests provide a variety of recreation pportunities. Users who hike, backpack, ski, tour, or iew scenery are generally attracted to forests whose atural appearance is little altered by human activities Calvin 1972). In contrast, hunters have best success where human activities are apparent—timber sales and ther areas readily accessible by roads. Fishing is most- y done in accessible lakes, reservoirs, and streams. Generally, most camping opportunities are at both publicly and privately developed sites served by roads. Most scenery viewing is by automobile on developed roads. Moreover, most of the winter use of snowmobiles for recreation in lodgepole pine forests is on roads. Finally, some forms of recreation, such as downhill skiing and mountain home development, require drastic modification of the natural forest landscape.

Clearcutting has the greatest visual impact and individual-tree selection has the least. However, variety typical of forests at the highest elevations—whose texture is broken by natural openings—is preferred to the monotony of vast, unbroken forest landscapes at middle and lower elevations (Kaplan 1973).

To enhance amenity values, openings cut for timber and water production and wildlife habitat improvement should be a repetition of natural shapes, visually tied together to create a balanced and unified pattern that will complement the landscape (Barnes 1971). This is especially important for openings in the middleground and background seen from a distance. Standard or simulated shelterwood, or individual-tree selection can be used to retain a landscape in foregrounds. Well planned clearcut openings also can be used to create vistas along well traveled road systems.

Individual-tree selection, group selection, and group shelterwood cutting are appropriate in high-use recreation areas, travel influence zones, scenic-view areas, and lands adjacent to ski runs—and also near support facilities and subdivision developments where permanent forest cover is desired. The visual impact of logging can be minimized by cleanup of debris and slash and by careful location of roads (Alexander et al. 1983).

COMPARISON OF CUTTING METHODS

No silvicultural system or cutting method (including no cutting at all) meets all resource needs. Cutting small openings provides maximum yields of timber at minimum costs, promotes the largest increases in water production without serious reduction in quality, produces diversity in food supply and cover favored by many wildlife species, and is necessary for the development of recreation sites for skiing and home subdivisions. Production and utilization of livestock forage are less than on larger openings, while clearcutting in any form destroys the habitat of wildlife species that dwell in closed forests. Clearcutting can create adverse visual effects if no thought is given to the size and arrangement of the openings; but it can also be used to create landscape variety that will enhance amenity values.

Standard and simulated shelterwood cutting also provide maximum timber yields over the same time interval, but at increased costs; they produce a wide range of wildlife habitats, but with less forage than openings and less cover than uncut forests. Water yields are increased over natural streamflow but less than with clearcutting small openings. Shelterwood cutting provides a partial retention of the forest landscape, but only when the overstory is retained for a long time.

Group selection and group shelterwood cutting, with the size of opening near the maximum, favor and discriminate against the same resource values as patch or strip clearcutting. They are more expensive and less flexible, however. Individual-tree selection cutting is not appropriate for timber production in pure lodgepole pine stands but could be used to meet other resource needs. Water yields are greater than from uncut forests. Individual-tree selection cutting provides minimum horizontal diversity in wildlife habitat, but favors species attracted to uncut forests. It also provides maximum partial retention of the natural forest landscape. Group selection with very small openings accomplishes about the same things as individual-tree selection.

Not all resource needs can be met on a given site, nor is any one cutting method compatible with all uses. Land managers must recognize the potential multiple-use values of each area, determine the primary and secondary uses, and then select the management alternative that is most likely to enhance or protect these values. On an individual site, some uses probably must be sacrificed or diminished to maintain the quantity and quality of others.

LITERATURE CITED

Alexander, Robert R. 1964. Minimizing windfall around clear cuttings in spruce-fir forests. Forest Science 10:130–142.

Alexander, Robert R. 1966a. Establishment of lodgepole pine reproduction after different slash disposal treatments. USDA Forest Service Research Note RM–62, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1966b. Harvest cutting old-growth lodgepole pine in the central Rocky Mountains. Journal of Forestry 54:113–116.

Alexander, Robert R. 1967. Windfall after clearcutting on Fool Creek—Fraser Experimental Forest, Colorado. USDA Forest Service Research Note RM–92, 11 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA Forest Service Research Paper RM–121, 88 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1975. Partial cutting in old-growth lodgepole pine. USDA Forest Service Research Paper RM–136, 17 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1977a. Regulation and control of cut under uneven-aged management. USDA Forest Service Research Paper RM–182, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1977b. Uneven-aged management of old-growth spruce-fir forests: Cutting methods and stand structure goals for initial entry. USDA Forest Service Research Paper RM–186, 12 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 19 Management of lodgepole pine in even-aged stands the central Rocky Mountains. USDA Forest Servi Research Paper RM–229, 11 p. Rocky Mountain For and Range Experiment Station, Fort Collins, Colo

Alexander, Robert R., James E. Lotan, Milo J. Larso and Leonard A. Volland. 1983. Lodgepole pi p. 63–66. *In* Silvicultural systems for major forest typ of the United States. R. E. Burns, technical compil U.S. Department of Agriculture, Forest Servic Agriculture Handbook 445, 191 p. Washington, D.

Alexander, Robert R., David Tackle, and Walter Dahms. 1967. Site indexes for lodgepole pine with co rections for stand density: Methodology. USDA Fore Service Research Paper RM–29, 24 p. Rocky Mou tain Forest and Range Experiment Station, Fort Co lins, Colo.

Amman, Gene D. 1978. The biology, ecology, and caus of outbreaks of the mountain pine beetle in lodgepo pine forests. p. 39–53. *In* Proceedings of symposiu [Pullman, Wash., April 25–27, 1978]. Darline L. Ki bee, Alan A. Berryman, Gene D. Amman, and Rona W. Stark, editors. University of Idaho Forest Wildli and Range Experiment Station, Moscow, Idaho.

Baker, Frederick S. 1949. A revised tolerance table. Jou nal of Forestry 47:179–181.

Barnes, R. Lawrence. 1971. Patterned tree harvest pr posed. Western Conservation Journal 28:44–47.

Basile, Joseph V., and Chester E. Jensen. 1971. Grazi potential on lodgepole pine clearcuts in Montan USDA Forest Service Research Paper INT–98, 11 Intermountain Forest and Range Experiment Statio Ogden, Utah.

Bates, Carlos G., Huber C. Hilton, and Theodo Krueger. 1929. Experiments in the silvicultural co trol of natural reproduction of lodgepole pine in t central Rocky Mountains. Journal of Agricultur Research 38:229–243.

Blyth, A. W. 1957. The effect of partial cutting on eve aged lodgepole pine stands. Canadian Department Northern Affiliation and Natural Resources, Fore Research Division, Technical Note 61, 14 p. Ottaw Ontario.

Bond, E. W. 1952. Growing stock differences in eve aged and all-aged forests. Journal of Forest 50:691–693.

Bourne, R. 1951. A fallacy in the theory of growing stoc Forestry 24:6–18.

Calvin, J. S. 1972. An attempt at assessing preferenc for natural landscapes. Environment and Behavi 4(4):447–470.

Clements, Frederick E. 1910. The life history of lodgepo pine burns. U.S. Forest Service Bulletin 79, 56 Washington, D.C.

Cole, Walter E., and Gene D. Amman. 1969. Mounta pine beetle infestations in relation to lodgepole pi diameters. USDA Forest Service Research No INT–95, 7 p. Intermountain Forest and Range Expe ment Station, Ogden, Utah.

rniss, R. L., and V. M. Carolin. 1977. Western forest insects. U.S. Department of Agriculture, Forest Service, Miscellaneous Publication No. 1339, 654 p. Washington, D.C.

ils, B. W., and W. R. Jacobi. 1984. Incidence and severity of Comandra blister rust on lodgepole pine in northwestern Wyoming. Plant Disease 68:1049–1051.

een, Allen W., and Duane D. Van Hooser. 1983. Forest resources of the Rocky Mountain states. USDA Forest Service Resource Bulletin INT–33, 127 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

atch, Charles R. 1967. Effect of partial cutting in overmature lodgepole pine. USDA Forest Service Research Note INT–66, 7 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

awksworth, Frank G. 1961. Dwarf mistletoe of ponderosa pine in the Southwest. U.S. Department of Agriculture Technical Bulletin 1246, 112 p. Washington, D.C.

awksworth, Frank G. 1975. Dwarf mistletoe and its role in lodgepole pine ecosystems. p. 342–358. *In* Management of lodgepole pine ecosystems. Proceedings of symposium. [Pullman, Wash., Oct. 9–11, 1973]. David M. Baumgartner, editor. Washington State University, Cooperative Extension Service, Pullman, Wash.

awksworth, Frank G. 1977. The 6-class dwarf mistletoe rating system. USDA Forest Service General Technical Report RM–48, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

awksworth, Frank G., and Oscar J. Dooling. 1984. Lodgepole pine dwarf mistletoe. U.S. Department of Agriculture Forest Insect and Disease Leaflet 18, 11 p. Washington, D.C.

awksworth, Frank G., and Donald P. Graham. 1963. Spread and intensification of dwarf mistletoe in lodgepole pine reproduction. Journal of Forestry 61:587–591.

awksworth, Frank G., and Thomas E. Hinds. 1964. Effects of dwarf mistletoe on immature lodgepole pine stands in Colorado. Journal of Forestry 62:27–32.

awksworth, Frank G., Thomas E. Hinds, D. W. Johnson, and T. D. Landis. 1977. Silvicultural control of dwarf mistletoe in young lodgepole pine stands. U.S. Department of Agriculture, Forest Service, Technical Report 122–10, 12 p. Rocky Mountain Region, Forest Insect and Disease Management, Lakewood, Colo.

epting, George H. 1971. Diseases of forest and shade trees of the United States. U.S. Department of Agriculture, Agriculture Handbook 386, 685 p. Washington, D.C.

oover, Marvin D., and Charles F. Leaf. 1967. Process and significance of interception in Colorado subalpine forest. p. 213–224. *In* Forest Hydrology. [International Symposium of Forest Hydrology, University Park, Pa., Aug–Sept., 1965]. W. E. Sooper and H. W. Lull, editors. 813 p. Pergamon Press, N.Y.

ornibrook, E. M. 1950. Estimating defect in mature and overmature stands of three Rocky Mountain conifers. Journal of Forestry 48:408–417.

Johnson, David W., Frank G. Hawksworth, and David B. Drummond. 1981. Yield loss of lodgepole pine stands to dwarf mistletoe in Colorado and Wyoming forests. Plant Disease 65:437–438.

Kaplan R. 1973. Predictors of environmental preferences. Designers and "clients". p. 265–274. *In* Environmental Design Research. Proceedings of 4th International EDRA Conference. [Blacksburg, Va., April, 1973]. W. F. E. Prieser, editor. Dowden, Hutchinson, and Ross, Stroudsburg, Pa.

Keen, F. P. 1952. Insect enemies of western forests. U.S. Department of Agriculture, Miscellaneous Publication 273, 280 p. Washington, D.C.

Krebill, R. G. 1965. Comandra rust outbreaks in lodgepole pine. Journal of Forestry 63:519–522.

Leaf, C. F. 1970. Sediment yields from central Colorado snow zone. American Society of Civil Engineering, Journal of Hydraulic Division 96(HY1):87–93, 97(HY2):350–351.

Leaf, Charles F. 1975. Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge. USDA Forest Service Research Paper RM–137, 31 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Leaf, Charles F., and Robert R. Alexander. 1975. Simulating timber yields and hydrologic impacts resulting from timber harvest on subalpine watersheds. USDA Forest Service Research Paper RM–133, 20 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

LeBarron, Russell K. 1952. Silvicultural practices for lodgepole pine in Montana. USDA Forest Service, Intermountain Forest and Range Experiment Station, Station Paper 33, 19 p. Ogden, Utah.

Lexen, Bert. 1949. Alternate clear-strip cutting in the lodgepole pine type. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Station Paper 1, 20 p. Fort Collins, Colo.

Lotan, James E., and William C. Critchfield. 1985. *Pinus contorta* Lodgepole pine. *In* Silvics of Native and Natural Trees of the United States and Puerto Rico. R. E. Burns, technical compiler. U.S. Department of Agriculture, Agriculture Handbook 270, (Rev.). Washington, D.C. (In press).

Lotan, James E., and Chester E. Jensen. 1970. Estimating seed stored in serotinous cones of lodgepole pine. USDA Forest Service Research Paper INT–83, 10 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Lotan, James E., and David A. Perry. 1977. Fifth-year seed:seedlings ratios of lodgepole pine by habitat type and seedbed preparation technique. USDA Forest Service Research Note INT–239, 6 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Lotan, James E., and David A. Perry. 1983. Ecology and regeneration of lodgepole pine. U.S. Department of Agriculture, Agriculture Handbook 606, 51 p. Washington, D.C.

Martinka, Robert R. 1972. Structural characteristics of blue grouse territories in southwestern Montana. Journal of Wildlife Management 36:489–510.

Mason, D. T. 1915a. The life history of lodgepole pine in the Rocky Mountains. U.S. Department of Agriculture Bulletin 154, 35 p. Washington, D.C.

Mason, D. T. 1915b. Utilization and management of lodgepole pine in the Rocky Mountains. U.S. Department of Agriculture Bulletin 234, 54 p. Washington, D.C.

McCambridge, William F., and Galen C. Trostle. 1972. The mountain pine beetle. U.S. Department of Agriculture, Forest Pest Leaflet 2, 6 p. Washington, D.C.

McCaughey, Ward W., and Wyman C. Schmidt. 1982. Understory tree release following harvest cutting in spruce-fir forests of the Intermountain West. USDA Forest Service Research Paper INT–285, 19 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Meyer, H. A. 1952. Structure, growth, and drain in balanced uneven-aged forests. Journal of Forestry 50:85–92.

Meyer, H. A., A. D. Recknagel, D. D. Stevenson, and R. A. Bartoo. 1961. Forest Management. 282 p. The Roland Press Company, New York, N.Y.

Mielke, J. L., R. G. Krebill, and H. R. Powers, Jr. 1968. Comandra blister rust on hard pines. U.S. Department of Agriculture, Forest Pest Leaflet 62, 8 p. (Rev.). Washington, D.C.

Moir, William H. 1969. The lodgepole zone in Colorado. American Midland Naturalist 81:87–98.

Myers, C. A., and M. J. Morris. 1975. Watershed management practices and habitat values in coniferous forests. p. 288–294. *In* Proceedings, Symposium on management of forest and range habitats for nongame birds. [Tucson, Ariz., May 6–9, 1975]. USDA Forest Service General Technical Report WO–1, 6 p. Washington, D.C.

Peterson, Roger S. 1960. Western gall rust on hard pines. U.S. Department of Agriculture Forest Pest Leaflet 50, 8 p. Washington, D.C.

Peterson, Roger S. 1962. Comandra blister rust in the central Rocky Mountains. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Research Note 79, 6 p. Fort Collins, Colo.

Pfister, Robert D., and R. Daubenmire. 1977. Ecology of lodgepole pine (*Pinus contorta* Dougl.). p. 27–46. *In* Management of lodgepole pine ecosystems. Proceedings, Symposium. [Pullman, Wash., Oct. 9–11, 1973]. David M. Baumgartner, editor. Washington State University, Cooperative Extension Service, Pullman, Wash.

Pfister, Robert D., and Philip McDonald. 1980. Lodgepole pine 218. p. 97–98. *In* Forest cover types of the United States and Canada. F. A. Eyre, editor. Society of American Foresters, Washington, D.C.

Regelin, Wayne L., and Olof C. Wallmo. 1978. Duration of deer forage benefits after clearcut logging of subalpine forest in Colorado. USDA Forest Service Research Note RM–356, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Regelin, Wayne L., Olof C. Wallmo, Julius G. Nagy, and Donald R. Dietz. 1974. Effect of logging on forage values for deer in Colorado. Journal of Forestry 72:282–285.

Reynolds, R. R. 1954. Growing stock in all-aged fores Journal of Forestry 52:744–747.

Roe, Arthur L., and Gene D. Amman. 1970. The mou tain pine beetle in lodgepole pine forests. USDA Fore Service Research Paper INT–71, 23 p. Intermounta Forest and Range Experiment Station, Ogden, Uta

Sartwell, Charles, R. F. Schmitz, W. J. Buckhorn. 197 Pine engraver, *Ips pini*, in the western States. U. Department of Agriculture, Forest Service, Forest Pe Leaflet 122, 5 p. Washington, D.C.

Scott, Virgil E., Glenn L. Crouch, and Jill A. Whela 1982. Responses of birds and small mammals to clea cutting in a subalpine forest in central Colorado. USD Forest Service Research Note RM–422, 6 p. Roc Mountain Forest and Range Experiment Station, Fo Collins, Colo.

Scott, Virgil E., Jill A. Whelan, and Robert R. Alexande 1978. Dead trees used by cavity-nesting birds on tl Fraser Experimental Forest: A case history. USD Forest Service Research Note RM–360, 4 p. Rocl Mountain Forest and Range Experiment Station, Fo Collins, Colo.

Stahelin, R. 1943. Factors influencing the natural restoc ing of high altitude burns by coniferous trees in tl central Rocky Mountains. Ecology 24:19–30.

Stottlemeyer, J. R., and C. W. Ralston. 1968. Nutrie balance relationships for watersheds on the Fraser E perimental Forest. p. 3:359–382. *In* Proceedings Nor American forest soils conference. [Raleigh, N.C., 196 North Carolina State University.

Tackle, David. 1955. A preliminary stand classificati for lodgepole pine in the Intermountain Region. Jou nal of Forestry 53:566–569.

Tackle, David. 1961. Silvics of lodgepole pine. USD Forest Service, Intermountain Forest and Range E periment Station, Miscellaneous Publication 19, 24 (Rev.). Ogden, Utah.

Tackle, David. 1964. Regenerating lodgepole pine central Montana following clearcutting. USDA Fore Service Research Note INT–17, 7 p. Intermounta Forest and Range Experiment Station, Ogden, Uta

Tackle, David. 1965. Ecology and silviculture of lodg pole pine. 1964:112–115. Proceedings of the Society American Foresters. [Denver, Colo., Sept. 27–Oct. 1964]. Washington, D.C.

Taylor R. F. 1939. The application of a tree classificati in marking lodgepole pine for selection cutting. Jou nal of Forestry 37:777–782.

Thompson, M. W. 1929. Timber growing and cutti practice in lodgepole pine region. U.S. Department Agriculture Bulletin 1499, 33 p. Washington, D.C.

Troendle, Charles A. 1982. The effects of small clearcu on water yield from the Deadhorse watershed; Frase Colorado. p. 75–83. *In* Proceedings, 50th annu meeting of the Western Snow Conference. [Reno, Ne April 19–23, 1982]. Colorado State University, Fort C lins, Colo.

Troendle, Charles A. 1983a. The Deadhorse experime A field verification of the subalpine water balan model. USDA Forest Service Research Note RM–42 7 p. Rocky Mountain Forest and Range Experime Station, Fort Collins, Colo.

endle, C. A. 1983b. The potential for water yield aug-
entation from forest management in the Rocky
ountain Region. American Water Resources Associa-
on, Water Resources Bulletin 19:359–373.

endle, Charles A., and Charles F. Leaf. 1981. Effects
f timber harvesting in the snow zone on volume and
ming of water yield. p. 231–243. *In* Proceedings, In-
erior West Watershed Symposium. [Spokane, Wash.,
pril 8–10, 1980]. David A. Baumgartner, editor and
ompiler. Cooperative Extension Service, Washington
tate University, Pullman, Wash.

endle, Charles A., and James E. Meiman. 1984. Op-
ions for harvesting timber to control snowpack ac-
umulation. p. 86–98. *In* Proceedings, 52nd annual
neeting of the Western Snow Conference. [Sun Valley,
daho, April 17–19, 1984]. Colorado State University,
ort Collins, Colo.

U.S. Department of Agriculture, Forest Service. 1971. Forest management in Wyoming. Timber harvest and the environment on the Teton, Bridger, Shoshone, and Bighorn National Forests. Wyoming Forest Study Team Report, 80 p. Washington, D.C.

U.S. Department of Agriculture, Forest Service. 1983. Silvicultural systems for the major forest types of the United States. R. E. Burns, technical compiler. U.S. Department of Agriculture, Agriculture Handbook No. 445, 191 p. Washington, D.C.

Wallmo, O. C. 1969. Response of deer to alternate-strip clearcutting of lodgepole pine and spruce-fir timber in Colorado. USDA Forest Service Research Note RM–141, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Wallmo, O. C., W. L. Regelin, and D. W. Reichert. 1972. Forage use by mule deer relative to logging in Colorado. Journal of Wildlife Management 36:1025–1033.

Alexander, Robert R. 1986. Silvicultural systems and cutting methods for old-growth lodgepole pine forests in the central Rocky Mountain. USDA Forest Service General Technical Report RM–127, 31 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting practices needed to convert old-growth and mixed lodgepole forests into managed stands. Guidelines consider stand conditions, succession, windfall risk, and insect and disease susceptibility. Cutting practices—clearcutting, shelterwood, and selection—are designed to integrate timber production with increased water yield, maintain water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic beauty.

Keywords: Silvicultural systems, timber harvesting, forest management, *Pinus contorta*

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-128**

Silvicultural Systems and Cutting Methods for Ponderosa Pine Forests in the Front Range of the Central Rocky Mountains

Robert R. Alexander

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Abstract

Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting practices needed to convert old-growth and mixed ponderosa pine forests in the Front Range into managed stands for a variety of resource needs. Guidelines consider stand conditions, and insect and disease susceptibility. Cutting practices are designed to integrate maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing, with providing wood products.

Cover Photo.—Open-grown Front Range.

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General Technical Report RM-128

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Silvicultural Systems and Cutting Methods for Ponderosa Pine Forests in the Front Range of the Central Rocky Mountains

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Contents

Page
NATURAL STANDS 1
  AGE-CLASS DISTRIBUTION 1
  REACTION TO COMPETITION 2
  STAND CONDITIONS 2
DAMAGING AGENTS 2
  WIND 2
  INSECTS 2
    Bark Beetles 2
    Other Insects 3
  DISEASES 3
    Dwarf Mistletoe 3
    Decay Fungi 4
    Other Diseases 4
  FIRE 4
  ANIMALS 4
CUTTING HISTORY 4
REGENERATION SILVICULTURAL SYSTEMS 5
  EVEN-AGED CUTTING METHODS 5
    Management with Advanced Reproduction 5
      Simulated Shelterwood Cutting 5
    Management for Regeneration After Cutting 6
      Clearcutting 6
      Shelterwood Cutting 6
  UNEVEN-AGED CUTTING METHODS 12
    Individual-Tree Selection Cutting 13
    Group Selection Cutting 13
    Stand Structure Goals 13
      Control of Stocking 13
      Maximum Tree Size 14
      Control of Diameter Distribution 14
    How to Determine Residual Stand Structure 14
    How to Handle Small Trees 17
    Marking Trees 17
    Recommendations for Selection Cutting 17
      Stand Structure Goals, Cutting Treatments, and Reentry Schedules 17
    Protecting the Residual Stand 18
COST OF SALE ADMINISTRATION AND LOGGING 18
MULTIPLE-USE SILVICULTURE 18
  POTENTIAL TIMBER YIELDS 18
  SOIL WATER RESOURCES 18
    Water Yield 18
    Soil Erosion 19
    Nutrient Loss and Stream Water Temperature Changes 19
  WILDLIFE AND RANGE RESOURCES 19
    Game Habitat 19
    Nongame Habitat 19
    Livestock Grazing 19
  RECREATION AND ESTHETICS 20
  COMPARISON OF CUTTING METHODS 20
LITERATURE CITED 20

Silvicultural Systems and Cutting Methods for Ponderosa Pine Forests in the Front Range of the Central Rocky Mountains

Robert R. Alexander

Ponderosa pine (*Pinus ponderosa* var. *scopulorum* ngelm.) (SAF Type 237), (Barrett et al. 1980) in the Front ange extends in a north-south direction along the east ope of the Rocky Mountains, from the Medicine Bow ational Forest in southern Wyoming through the rapaho-Roosevelt, Pike-San Isabel, and Rio Grande Naonal Forests in Colorado, to the Carson National Forest northern New Mexico (fig. 1). These timberlands ocupy about 4 million acres that include grassland parks, illow fields along streams, sagebrush and oakbrush eas, and scattered cultivated fields (Gary 1985). They e continuously heavily used, because they are accessile all year for residence, recreation, and other activities yers 1974).

The principal values derived from these forests are the enic beauty of the landscape and various outdoor ecreation opportunities. These forests also are impornt habitat for a variety of wildlife, provide forage for vestock, and maintain watershed protection in an area here erosion is potentially serious following any mar disturbance of the vegetative cover. Low fertility of ost soils in the Front Range results in timber producon potentials that vary from below average to very low. ood products produced during treatment of forested eas for various management objectives support a small ood-products industry.

NATURAL STANDS

GE-CLASS DISTRIBUTION

There is a serious imbalance in age-class distribution natural ponderosa pine in the Front Range. For exnple, in Colorado, about 60% of the stocked area is in wtimber sized stands (Green and Van Hooser 1983). uch of these stands are overmature and declining in eneral vigor and soundness. If they are not replaced to eate future scenic beauty and recreational areas, they ill become more unattractive (Myers 1974).

Twelve percent of the ponderosa pine is in poletimber ands. Much of the poletimber is in dense patches or ands on areas of low site quality that are or will become agnated if left untreated. Many of these stands became stablished after cutting or wildfires in the late 1800s. ecause fires are random events, poletimber stands are undant in some areas and rare in others. Only about % of the Front Range ponderosa pine is classified as edling and sapling stands that originated after cutting fire. About one-fourth (27%) of the ponderosa pine nds are classified as nonstocked. Failure of reproduction after cutting or fire accounts for some of the nonstocked area; but not all nonstocked lands can support ponderosa pine forests; or else they can support only open grown, low density forests (Green and Van Hooser 1983).

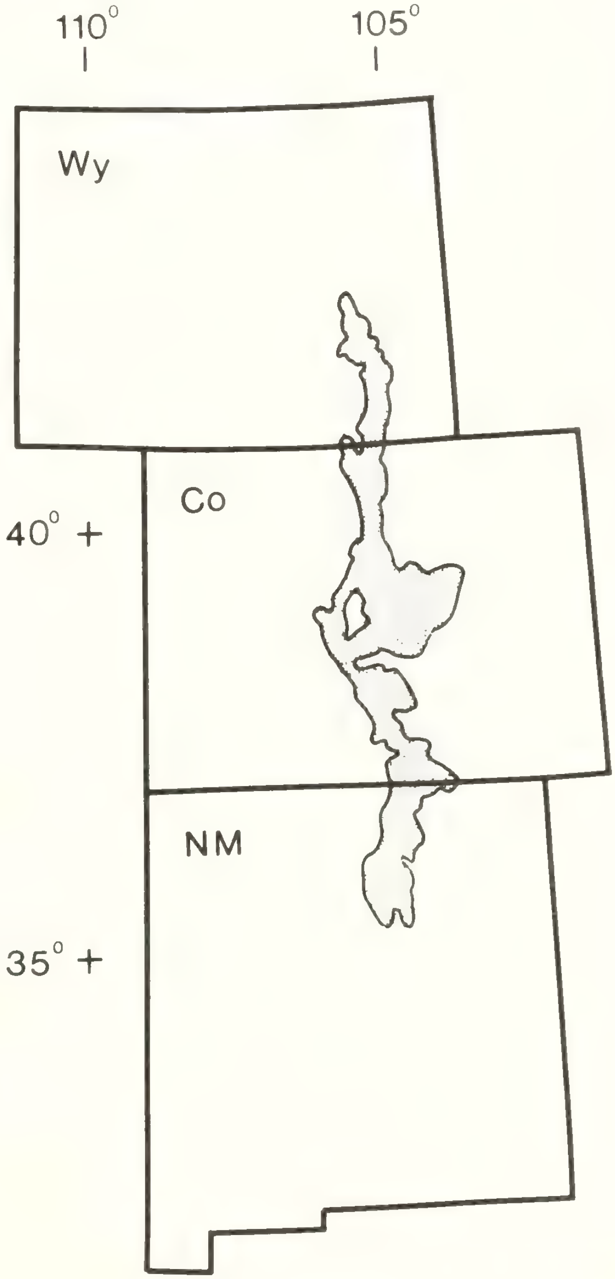


Figure 1.—Distribution of ponderosa pine in the Front Range.

REACTION TO COMPETITION

Ponderosa pine is rated shade-intolerant (Baker 1949). It is comparable in shade tolerance to lodgepole pine (*Pinus contorta* Dougl. ex Loud.) but is more intolerant than associates such as Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and blue spruce (*Picea pungens* Engelm.). It is not as intolerant as aspen (*Populus tremuloides* Michx.), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), and pinyon pine (*Pinus edulis* Engelm.), frequent associates in the Front Range.

Ponderosa pine in the Front Range occurs as a climax type between 6,500 and 9,000 feet elevation; but fire and/or logging has partially or completely converted many climax ponderosa pine stands to other plant communities. The kind of vegetation initially occupying the site usually determines the time it will take to return to a ponderosa pine forest. At higher and lower elevations, where ponderosa pine integrates into mixed conifer and pinyon-juniper forests, it loses its climax characteristics (Schubert 1974).

STAND CONDITIONS

Ponderosa pine forests in the Front Range form a mosaic of variations in tree size and stand density (fig. 2). They are often open-grown and poorly stocked, although many stands, patches, and groups of trees are overstocked. These forests occur mainly as irregular, multistoried stands consisting of small, even-aged groups of trees that simulate the arrangement attainable from either group selection or group shelterwood. Each even-aged group usually covers an area of 1/2 to 1 acre. Other stands are made up of patches smaller than 5 acres but larger than 1 acre. They are too large to simulate group selection or group shelterwood. Some stands appear to be single-storied and even-aged and simulate stands regenerated by clearcutting, shelterwood, or seed-tree cutting. Other stands are two-storied and resemble the seed cut of a two-cut shelterwood. These stands may appear to be highl irregular before treatment. Cutting necessary to improv the health, vigor, and appearance of such stands pr duces a greater uniformity in density and age structur (Myers 1974).

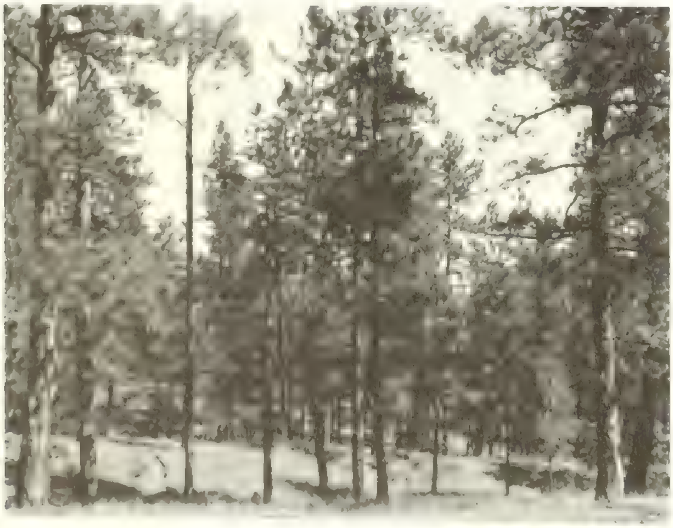


Figure 2.—Ponderosa pine in the Front Range forms a complex mosaic of different tree sizes and stand densities.

Ponderosa pine in the Front Range is frequently pur pine over much of the area it occupies; but mixed stand of pine and other species are not uncommon. In pur stands of ponderosa pine, there may or may not be a understory of reproduction, depending on the densit of the overstory. If this advanced growth has not bee suppressed for a long time, it will respond to release. I mixed stands, the overstory may be pure pine or pi and Douglas-fir at the middle and higher elevations o north slopes, and pine or pine and pinyon-juniper lower elevations. Advanced growth of Douglas-fir n damaged by western spruce budworm (*Choristoneura o cidentalis* Freeman) will respond to release and mak good growth. In mixed ponderosa pine—pinyon-junip stands, there is seldom any tree reproduction in th understory.

DAMAGING AGENTS

WIND

Ponderosa pine has a well-developed root system an is one of the more windfirm species in the central Rock Mountains. Although wind is not a primary cause damage to ponderosa pine in the Front Range, it can b damaging locally, especially in mature to overmatu stands during windstorms accompanied by hea precipitation. Generally, wind risk is not an importa consideration in cutting ponderosa pine. Exceptions a those topographic situations of very high wind risk, su as ridgetops, upper windward slopes, and saddles ridges with shallow soils; stands with many trees wi defective boles and root systems; and dense stands gro ing on sites with a high water table.

INSECTS

Bark Beetles

Many species of insects infest ponderosa pine (Steve et al. 1980); but the mountain pine beetle (*Dendrocton ponderosae* Hopk.) is the most serious pest in mature overmature ponderosa pine stands in the Front Ran (Stevens et al. 1975). Epidemics have occurred throug out recorded history, and a severe outbreak in Colora only recently subsided (fig. 3).

Adult beetles attack ponderosa pine in midsumme usually July 15 to September 15. The beetles carry blu stain fungi that hastens the death of the tree. Beetl create egg galleries, mate, and deposit eggs in the phloe layer. Larvae then feed on the phloem, and in conjun tion with blue-stain fungi, girdle and kill the tree. T first indications of attack are pitch tubes on the tru where the beetles have entered, and brownish dust the bark crevices and around the base of the tree. Tre riously attacked in the summer die almost immediate- but usually do not begin to fade until the following ring. Needles change from green to yellow-green, sor- l, and finally rusty brown before dropping off years ter. During outbreaks, mountain pine beetles usually ll trees in groups rather than individual trees scattered roughout the stand. These groups enlarge as subse- uent generations of beetles continue the infestation, or ew adjacent groups may be attacked. Groups may vary om 2 or 3 to 100 or more trees (McCambridge and Tros- e 1972, Stevens et al. 1975).

All stands are not equally susceptible to attack. pidemic outbreaks usually are associated with stands which most of the trees are 6 inches in diameter and rger, and which are overcrowded and under stress. In- stations do not usually begin in trees smaller than 6 ches d.b.h.; but as groups of trees are killed, smaller ees, intermingled with larger trees, may be attacked and lled. Although natural factors, such as a sudden lower- g of fall temperatures or prolonged subzero winter mperatures, nematodes, woodpeckers, and parasites ay reduce populations, they cannot be relied upon to ntrol outbreaks (McCambridge and Trostle 1972). irect control of outbreaks with chemicals is expensive nd often only a holding action until potentially suscep- ble trees can be cut. High value trees in campgrounds nd recreation areas may be protected by preventative rays.

The red turpentine beetle (*Dendroctonus valens* eConte) attacks the base of trees and freshly cut logs nd stumps of ponderosa pine (Furniss and Carolin 977). It is not an aggressive tree killer but frequently eakens trees, making them susceptible to other bark etles. Populations may increase in areas where logging as occurred for several consecutive years and then may ove to adjacent stands. Attacks are characterized by ddish pitch tubes on the lower portion of the stem and eavy frass around the base of the tree. Damage is seldom rious enough to warrant treatment except in high-value eas. Chemical control is the most effective way to con- ol these beetles.

The pine engraver beetles (*Ips* spp.) are also potential- destructive bark beetles although they are normally secondary insects in the Front Range (Stevens et al. 1980). Pine engraver populations commonly develop in logging slash, especially if it is shaded or does not dry out quickly for other reasons. The most effective control is removing or burning large slash and exposing small slash to direct sunlight and wind so it dries rapidly (Sartwell et al. 1971).

gure 3.—Mountain pine beetle infestations kill trees and reduce the attractiveness of ponderosa pine.

Other Insects

Other insect pests generally do not cause widespread losses but can be locally serious. Tip and shoot moth larvae may cause distorted or forked crowns and dead terminals and lateral shoots; sawflies, pine butterflies, and pandora moths can defoliate trees. Control of these insects is usually expensive and difficult.

DISEASES

Dwarf Mistletoe

Dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodium* (Engelm.) Hawksworth and Wiens) is one of the most serious diseases affecting ponderosa pine in the Front Range of Colorado and New Mexico (fig. 4). It is present on about 20% of the ponderosa pine acreage in the Front Range National Forests (Johnson et al. 1984). Dwarf mistletoe reduces growth and seed production and increases mortality. The rate of mortality depends largely on the age of the host tree when attacked. Young trees die quickly, while older trees with well-developed and vigorous crowns may not show appreciable effects for years. Dwarf mistletoe is most damaging in stands that have been partially opened up by cutting, mountain pine beetles, or windfall and of least consequence on regenerated burns following catastrophic fires. Heavily infected old-growth stands frequently have less than 50% of the volume of comparable uninfected stands.

Dwarf mistletoe is a parasitic plant that flowers in April and May. At maturity (July and August), fruits are forcibly ejected for distances up to 30 feet. Seeds are covered with a gelatinous material, which acts as a lubricant when wet from rain, and facilitates movement from pine needles onto branches where infection takes place. Rate of spread of dwarf mistletoe is slow—about 1.7 feet per year in open and 1.2 feet per year in dense, immature stands (Lightle and Weiss 1974).

The disease is difficult to detect in recently infected stands, because trees show no abnormalities except for the inconspicuous shoots on branches and main stems. Where the parasite has been present for a long time, stands will have one or more heavily damaged centers characterized by many trees with witches' brooms, spiketops, and an above-average number of snags with remnants of brooms (Lightle and Weiss 1974). Although optimum development is favored by a vigorous host, and the most vigorous trees are most heavily infected, frequency of infection is usually higher on poor sites.

To quantify the severity of infection, Hawksworth (1961, 1977) developed the 6-class mistletoe rating system (fig. 5). Average stand rating is computed by averaging the dwarf mistletoe ratings (DMR) for all trees in the stand, including noninfected trees. Average stand DMRs in untreated stands can be estimated from the percentage of tree infection in the stand. The relationship of average stand DMR to proportion of trees is as follows:

Percent of trees infected	DMR
10	0.17
20	0.24
30	0.35
40	0.52
50	0.76
60	1.11
70	1.62
80	2.37
90	3.46
100	5.06

Decay Fungi

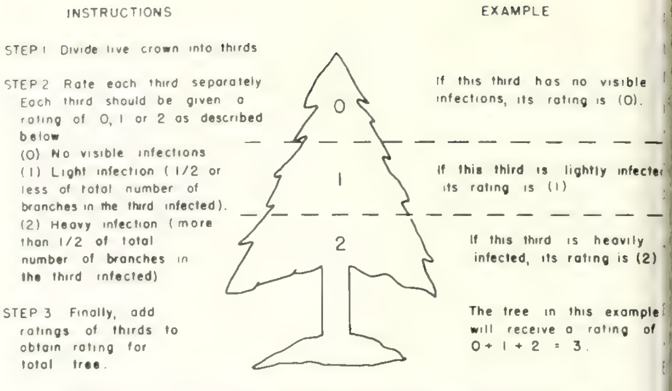
The major root and stem fungi attacking ponderosa pine in the Front Range are red rot (*Dichomitus squalens* (Karst.) Reid) and Armillaria root disease (*Armillaria mellea* (Vahl:Fr.) Quel.) (Hepting 1971).

As old-growth is converted to managed stands, decay fungi can be expected to decrease. Early removal of ponderosa pine with known indicators of defect will help to establish healthy, vigorous forests with greater growth potential. Rot losses in future stands can be minimized by shorter cutting rotations—120 years. Close supervision of logging operations to reduce mechanical injuries will minimize points of entry for decay fungi. Proper slash disposal will lower inoculum potential of rot fungi in residual stands. These sanitation measures are important, because direct control of rots are not possible.

Other Diseases

Limb rust (*Peridermium filamentosum* Pk.) kills ponderosa pine throughout its range. It is a systemic disease which spreads throughout the tree. The rust normally occurs in older trees and is always fatal (Petersor and Shurtleff 1965). Other diseases that attack ponderos pine are of minor significance.

Figure 4.—Heavy dwarf mistletoe infestions reduce growth and scenic beauty.



STEP 1 Divide live crown into thirds

STEP 2 Rate each third separately Each third should be given a rating of 0, 1 or 2 as described below
(0) No visible infections
(1) Light infection (1/2 or less of total number of branches in the third infected).
(2) Heavy infection (more than 1/2 of total number of branches in the third infected)

STEP 3 Finally, add ratings of thirds to obtain rating for total tree.

If this third has no visible infections, its rating is (0).

If this third is lightly infecte its rating is (1)

If this third is heavily infected, its rating is (2)

The tree in this example will receive a rating of 0 + 1 + 2 = 3.

Figure 5.—The 6-class dwarf mistletoe rating system.

FIRE

The effect of fire on the character of ponderosa pin stands depends upon the age and density of the stan and the intensity of the fire. Low intensity ground fire damage dense seedling, sapling, and pole stands; bu older trees are quite resistant. High intensity crown fire destroy all trees in the burned area. Many large tree have fire scars which reduce the value of the butt log Dense young stands should be thinned to reduce th probability of crown fires. Fuel breaks should be place along heavily traveled roads and around high value sites

Controlled or prescribed burning has not been use much in ponderosa pine forests in the Front Range bu offers a management opportunity in mature stand without a stand of advanced reproduction. Low intensity surface fires can be used to prepare seedbeds, reduc competing vegetation, and eliminate fire hazards withou damage to the residual stand.

ANIMALS

Animal damage to established ponderosa pine forest is usually more severe in young trees; but damage t older trees can be serious. Mule deer (*Odocoileus hemionus* Rafinesque) and elk (*Cervus* elaphus L.) ma browse ponderosa pine. Porcupines (*Erethizon dorsatur* Brandt) may cause serious damage by girdling trees; bu losses are usually localized. At times, twig cutting b abert squirrels (*Sciurus aberti* Woodhouse) can be sever enough to kill trees or weaken them to the point that ir sects and diseases cause death.

CUTTING HISTORY

Cuttings of ponderosa pine in the Front Range first occurred about 1860 (Clapp 1910, Pearson 1912). Durin the Gold Rush, many thousands of acres were virtuall clearcut for fuel, mine timbers, and lumber. Pionee anchers also used ponderosa pine for fuel, fence posts, nd lumber. Areas not clearcut were high graded on a elective basis. Many of the clearcut areas were subseuently burned and are now poorly stocked with secondrowth or are nonstocked. Following World War I, some orm of partial cutting became standard practice on naional forests. However, some diameter limit (10- to 2-inch minimum) cuttings were still made on private ands. Cuts on national forest lands averaged about 50% f the volume, primarily removing mature and decadent ees (Schubert 1954).

On many national forests, "selective cuttings" were made in a series of light cuts which generally amount o a shelterwood (Clapp 1910, Pearson 1912). These light uts eventually removed 60% to 70% of the volume. A emoval cut was made 10 to 20 years later, after eproduction became established.

Foresters recognized early the importance of the group nd/or irregular stand structure common to ponderosa ine in the Front Range, and the need to modify cutting ractices to take advantage of "natural" stand structure nd constrain cutting in areas where reproduction was ot already established. Another need was for sanitation alvage cutting to reduce heavy natural mortality of the arger and older trees caused by lightning, dwarf mistletoe, and bark beetles (Schubert 1974).

In the early 1940s, sanitation salvage cutting was enerally replaced by individual-tree selection (improvement selection) aimed at improving the quality, reducng the density of growing stock, and salvaging mortaly. In the early 1960s, cutting shifted to (1) a modified helterwood with the first cut either a seed cut or a final emoval, depending upon the amount of reproduction n the stand, with the objective of maintaining the presnt irregular stand structure and diversity between and within vegetative types; (2) thinning dense even-aged roups and/or stands; and (3) removal of badly diseased r dying trees that overtopped future growing stock.

Past logging, insect and disease problems, fires, and rregularities of reproduction resulting from the variabiliy of weather generally have left ponderosa pine forests n the Front Range with little resemblance of managed, egulated forests (Myers 1964). However, in recent years, ome progress has been made with sanitation and imrovement cuts. While forests still are not regulated, ignificant progress toward managed stand conditions as been made in more accessible areas.

REGENERATION SILVICULTURAL SYSTEMS

Ponderosa pine forests in the Front Range can be arvested by both even- and uneven-aged silvicultural ystems. They can be harvested by all even- and unevenged cutting methods and their modifications. However, ot all cutting methods are recommended. Clearcutting n patches is an effective method of controlling dwarf mistletoe and mountain pine beetles; but regeneration uccess has been varied. Similarly, the seed-tree method as not been successful in regenerating ponderosa pine. ndividual-tree selection can be applied to some stands; ut the silvical characteristics and the stand conditions of ponderosa pine in the Front Range are not generally suited to individual-tree selection cutting (Ronco and Ready 1983). The objective of each regeneration system is to harvest the timber crop and obtain adequate reproduction. The choice of cutting method in ponderosa pine stands depends upon management goals; but stand conditions, disease and insect susceptibility, and the risk of potential fire damage that vary from place to place on any area limit the options available for handling individual stands. Furthermore, the economics of harvesting, manufacturing, and marketing wood products from many small diameter trees in the central Rocky Mountains further limits cutting practices. Cutting to bring ponderosa pine in the Front Range under management is likely to be a compromise between what is desirable and what is possible. Management on many areas may involve a combination of several cutting treatments (Myers 1974).

EVEN-AGED CUTTING METHODS

Shelterwood is the preferred even-aged method for ponderosa pine in the Front Range, in stands where disease and insect problems do not require clearcutting.

Management with Advanced Reproduction

Simulated Shelterwood Cutting

This cutting method, generally applicable to two-storied stands, removes the overstory from a manageable stand of advanced reproduction. It simulates the final harvest of a standard shelterwood.

Stands may be pure ponderosa or mixed with a ponderosa pine overstory and a pine/Douglas-fir understory. Understory trees respond to release after cutting; but wide variations in age, composition, quality, and quantity of advanced reproduction require careful evaluation of the potential for future management. One course of action is followed if the advanced reproduction is to be managed, another if a manageable stand is not present, cannot be saved, or the manager chooses to destroy it and start over.

Prelogging evaluation.—The initial examination must answer the following questions: (1) How much of the area is stocked with acceptable seedlings and saplings, and will that stocking insure a satisfactory replacement stand? (2) Can it be logged economically by methods that will save advanced reproduction? Is the timber volume too heavy to save advanced reproduction if it is removed in one cut? (3) How much of the area will require subsequent natural or artificial regeneration, either because advanced reproduction is not present or will be damaged or destroyed in logging?

Because any kind of cutting is likely to destroy at least 50% of the advanced growth, a manageable stand of advanced reproduction before cutting should contain at least 600 acceptable seedlings and saplings per acre. Stands or portions of stands not meeting these criteria have to be restocked with subsequent natural or artificial regeneration.

Cutting and slash disposal treatment.—Mature and overmature trees should be cut to release advanced reproduction and harvest merchantable volume. Seed sources need not be reserved from cutting unless required for fill-in stocking. The size, shape, and arrangement of units cut is not critical for regeneration; but to be compatible with other key uses, they should be irregular in shape.

Protection of advanced reproduction begins with a well-designed logging plan. Logging equipment and activity must be rigidly controlled to minimize damage to advanced reproduction and disturbance to soil. Skidroads should be located at least 200 feet apart and marked on the ground before cutting. Skidding equipment should be moved only on skidroads. Where possible, trees should be felled into openings at a herringbone angle to the skidroad to reduce disturbance when logs are moved onto the skidroad. It may be necessary to deviate from a herringbone felling angle in order to drop the trees into openings. In this case, the logs will have to be bucked into short lengths to reduce skidding damage. Furthermore, the felling and skidding operations must be closely coordinated, because it may be necessary to fell and skid one tree before another is felled. Dead sound material and snags that are felled should be skidded out of the area to minimize the amount of slash and unmerchantable material. In stands with heavy volumes per acre, it may be necessary to remove the overstory in more than one cut.

Slash treatment then should be confined to areas of heavy concentrations as required for protection from fire and insects or preservation of esthetic values. Slash also must be treated carefully to avoid damage to advanced reproduction. If trees are felled into openings as much as possible, a minimum of turning and travel with brush dozers will be needed to concentrate the slash for burning. Slash piles should be large enough to confine burning to the smallest total area possible.

Postlogging reevaluation.—Even with careful logging and slash treatment, some advanced reproduction will be damaged or destroyed. The area must be surveyed to: (1) Determine the extent of damage to the reproduction. At least 300 acceptable seedlings and saplings per acre must have survived to consider the area adequately stocked. This is in addition to any trees larger than 4 inches d.b.h. that survived. Areas that do not meet these standards need fill-in or supplemental stocking. (2) Plan stand improvement—cleaning, weeding, and thinning—to release crop trees. Cutover areas should not be considered in an adequate growing condition until the crop trees are free to grow and the necessary fill-in planting or natural regeneration is complete.

Management for Regeneration After Cutting

Clearcutting

This method harvests the timber crop in one step to establish a new stand. Clearcutting ponderosa pine in the Front Range is not recommended, except where there is no alternative for solving severe insect and disease problems, discussed later.

Shelterwood Cutting

This method harvests a timber stand in a series of cuts It is applicable to single-storied ponderosa pine or two storied stands without a manageable stand of advanced reproduction. In a standard shelterwood, the new stand regenerates under the shade of a partial overstory canopy. The final harvest removes the shelterwood and permits a new stand to develop in the opening. Group shelterwood (a modification of the shelterwood method is applicable in stands composed of irregular mosaic of small even-aged groups or poles of trees. The new stand regenerates in small openings that leave standing trees around the margins as a seed source. Openings are too small (2 acres or less) to be classified as a clearcut This kind of cutting has been incorrectly called modified group selection but differs from a selection cu in the way the growing stock is regulated.

These cutting methods are usually the only even-aged options available for ponderosa pine in the Front Range However, shelterwood cutting requires careful marking of individual trees or groups of trees to be removed and close supervision of logging. The following recommen dations for shelterwood cutting practices are keyed t broad stand descriptions based largely on experience and disease and insect problems (Myers 1974, Ronco and Ready 1983, Schubert 1974). Practices needed to obtain natural reproduction are also discussed. Stands are pur pine unless otherwise indicated.

Single- and two-storied stands.—Single-storied stand may appear to be even-aged and two-storied stands two aged (fig. 6), but often contain more than one or two ag classes; occasionally they may even be broad-aged. even-aged in appearance, there is a small range diameter and crown classes. In single-storied stand codominants form the general level of the canopy; bu the difference in height between dominants, codomi nants, and intermediates is not great. In two-storied stands, top story resembles a single-storied stand. Th second story is composed of younger trees of small

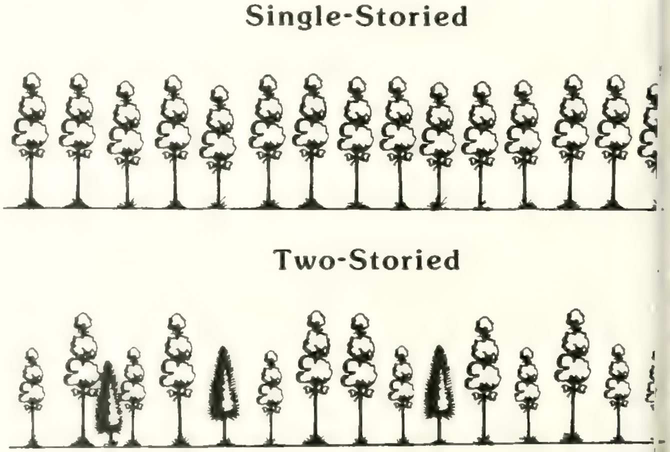


Figure 6.—Single- and two-storied ponderosa pine stands.

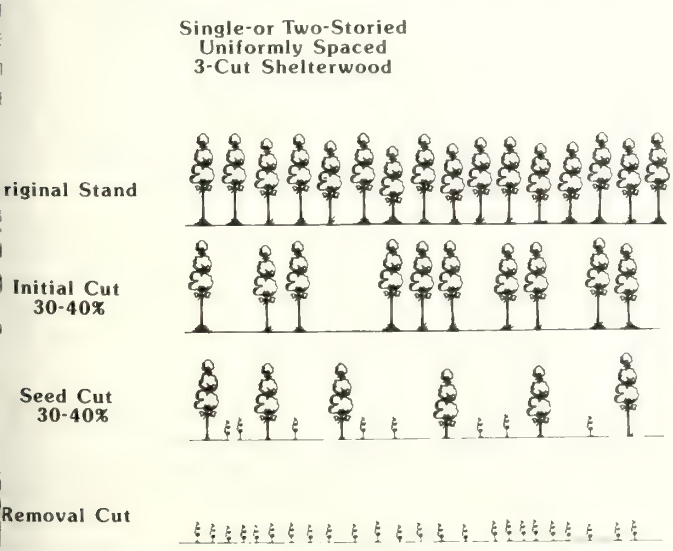
iameter. If the stand is two-storied and more than two-ged, the overstory usually contains at least two ages asses. The younger trees are finer limbed and are naller in diameter. Stocking of single-storied stands ay be uniform. Stocking of the overstory in two-storied ands may be irregular; but overall stocking may appear be uniform. A manageable stand of advanced eproduction usually is absent.

In mixed single-storied stands, the overstory is either) pure pine or (2) pine and Douglas-fir, with advanced eproduction largely Douglas-fir that may or may not be manageable stand. In mixed two-storied stands, the verstory usually is pure pine but may be pine and ouglas-fir. The second story usually is mixed pine and ouglas-fir but may be largely Douglas-fir. Stocking in ixed stands varies from uniform to irregular.

A two-cut shelterwood usually is appropriate in stands hat have been previously entered. A three-cut shelter-vood often is more desirable in stands not previously ntered, especially those susceptible to windthrow.

Using a three-cut shelterwood in stands that are niformly spaced, the first entry should remove 30% to 0% of the basal area on an individual-tree basis (fig. 7). his initial entry is a preparatory cut, because it probably oes not open up the stand enough for pine reproduc-on to become established significantly. The general evel of the canopy should be maintained by removing ome trees in each overstory crown class. The cut should ome from the poorest vigor class trees; but openings rger than one tree height in diameter should be avoided y distributing the cut over the entire area. In mixed tands, if the overstory is mostly pine, handle it as a pure tand; if the overstory is of mixed composition, cut as uch of the basal area recommended in pine as is possi-le to release the Douglas-fir, provided there are no erious budworm problems.

The second entry into the stand can be made in 5 to 0 years after the first cut. The second cut should remove 0% to 40% of the original basal area on an individual-ee basis. This seed cut opens up the stand so that pine regeneration can become established. The largest and most vigorous dominants and codominants should be reserved as a seed source; but avoid cutting openings in the canopy larger than one tree height in diameter by distributing the cut over the entire area, even if it means leaving trees in the C and D vigor classes with poor seed production potential. In mixed stands, cut as much of the recommended basal area in pine as is possible without creating openings larger than one tree height.



igure 7.—Sequence of entries with a 3-cut shelterwood in a uniformly spaced, single- or two-storied ponderosa pine stand.

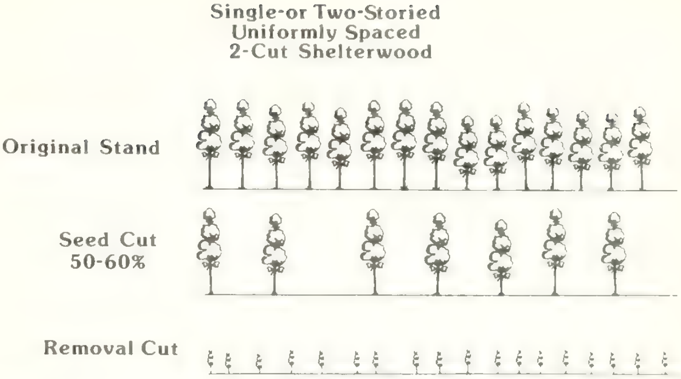


Figure 8.—Sequence of entries with a 2-cut shelterwood in a uniformly spaced, single- or two-storied ponderosa pine stand.

The last entry into these uniformly spaced stands is the final harvest which should remove all of the remaining original overstory. It should not be made until a manageable stand of reproduction has become established; but the cut should not be delayed beyond this point because the overwood (1) hampers the later growth of seedlings, and (2) if infected with dwarf mistletoe, it will reinfect the new stand.

The manager also has the option of removing less than 30% of the basal area at any entry and making more entries; but they should be made at more frequent intervals. The cut will be spread out, and continuous high forest cover will be maintained for a longer time. This option is not recommended where mountain pine beetles and dwarf mistletoe limit how stands can be handled.

Using a two-cut shelterwood in stands that are uniformly spaced, the first cut can remove up to 50% to 60% of the basal area (fig. 8). About 50% of this cut should come from the second story of a two-storied stand, because it is necessary to reserve some of the better dominants as a seed source. This cutting is the seed cut; but trees are marked on an individual-tree basis. Trees removed should be in vigor classes C and D insofar as possible; but selected dominants and codominants should be left even when they are in vigor classes C and D if they do not have dead or dying tops. Avoid cutting holes in the canopy by distributing the cut over the entire area. In mixed stands, if the top story or the first and second stories are pure pine, handle them as pure stands. If the top story is of mixed composition, cut as much of the basal area to be removed in pine as is possible to release the Douglas-fir; but do not cut all of the pine if it is needed to maintain the overstory.

The second entry should be the final harvest to remove the remaining original stand and release the reproduction. It cannot be made until the new stand of reproduction is established.

The manager has other options, including cutting less than the recommended basal area, making more entries, and spreading the cut out over a longer time by delaying the final harvest until the new stand is tall enough to create the appearance of a high forest. This is not recommended where mountain pine beetles and dwarf mistletoe limit how stands can be handled.

For stands with clumpy or irregular spacing, using either a two- or three-cut group shelterwood, the usual uniform arrangement of individual trees in single-storied stands is less likely to occur in ponderosa pine in the Front Range than in other Rocky Mountain timber types. Natural openings occur in many single-storied and two-storied stands. In other clumpy or irregularly-spaced stands, openings may have resulted from the break-up of single-storied stands, beetle attacks, or fires.

With a three-cut alternative, the first entry should remove about 30% of the basal area using a group shelterwood (fig. 9). Openings should be kept small and should conform to the natural arrangement of the stands; but not more than one-third of the area should be cut over at any one time. The second entry into the stand should not be made until the first openings have been regenerated. This cut should remove about 30% to 40% of the original basal area without cutting over more than an additional one-third of the area. The final entry should remove the remaining groups of merchantable trees.

With a two-cut alternative, the first cut can remove about 40% to 50% of the basal area in a group shelterwood (fig. 10). The group openings can be two or three times tree height; but the area cut over should not exceed about one-half of the total. Openings should be irregular in shape to simulate natural openings. One additional entry can be made in the stand to remove the remaining original basal area in group openings up to two to three times tree height.

With both alternatives, the timing of the final entry depends on how the manager decides to regenerate the openings. Using natural regeneration, the final harvest either must be delayed until the trees in the original openings are large enough to provide a seed source, or thes
openings are planted, or a standard shelterwood is a
plied to the last groups. In the last case, it will requi
at least one additional entry to remove the overstory aft
reproduction has established.

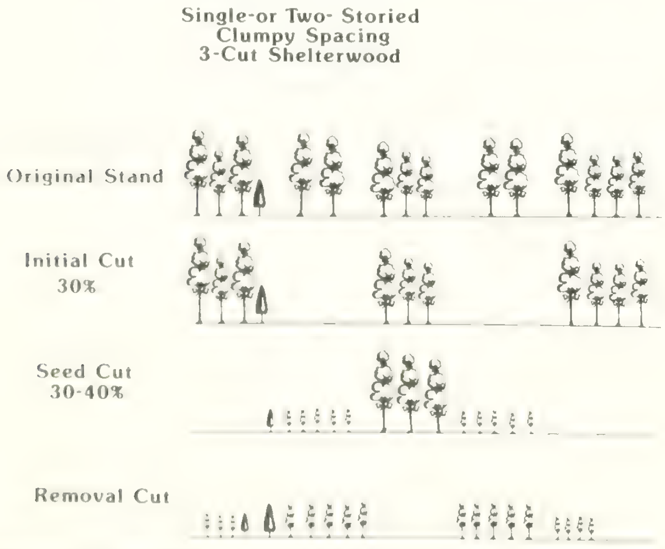


Figure 9.—Sequence of entries with a 3-cut group shelterwood in an irregularly spaced, single- or two-storied ponderosa pine stand.

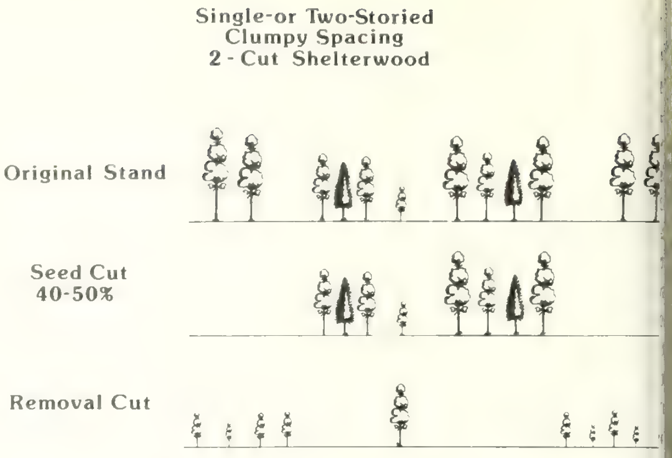


Figure 10.—Sequence of entries with a 2-cut group shelterwo
in an irregularly spaced, single- or two-storied ponderosa pine stan

With either alternative, the manager may choose t
remove less than the recommended basal area an
cut over less than the recommended area at any tim
This will require more entries and spread the cut ov
a longer time; but each new cut should not be made u
til the openings cut the previous entry have regenerate
Furthermore, the last groups cannot be cut until the
is either an outside seed source, the openings are plante
or a standard shelterwood is applied to the last group

Group shelterwood cutting is not applicable in pu
stands where mountain pine beetle or dwarf mistlet
impose limitations, because the interval between initi
cutting and final harvest is likely to be too long to pr
vent serious mistletoe infection of new reproducti
and/or loss of beetle-susceptible trees.

Multistoried stands.—These stands usually a
uneven- to broad-aged (fig. 11), with an irregular mosa
of small even-aged patches of trees of less than 5 acr
or small even-aged groups of trees each less than 1 acr
If stands developed from relatively few individuals aft
disturbance, the overstory trees are coarse limbed. Fi
in trees are better formed and finer limbed. Vigor of t
overstory trees varies from poor to good. In stands th
developed from deterioration of single- or two-stori
stands, the overstory trees may be no limbier than t
fill-in trees. Nearly all of the healthy, faster growing tre
are below saw-log size. Stocking may be irregular with
patches or groups. A manageable stand of advance
reproduction may be present.

In mixed stands, the overstory may be either (1) pu
pine, or (2) a mixture of pine and Douglas-fir. Stocki
in mixed stands is likely to be irregular. Mixed stan
frequently have a manageable stand of advanced repr
duction of species other than pine.

There is considerable flexibility in harvesting the
multistoried stands. They can be managed as either eve
or uneven-aged.

To convert irregular multistoried stands composed of mosaic of even-aged groups and/or patches to even-ed stands, groups and patches that differ only modately in diameter classes are combined into stands and en cut to create a greater uniformity in diameter classes g. 12). Dense groups or patches of immature trees ould be thinned to reduce stand density (fig. 13). Emiasis should be on thinning from below with the moval of enough dominants and codominants to stimate growth. Immature groups and/or patches not dense iough to require thinning should receive an improveent cut to remove diseased and dying trees and any attered remnant overstory trees left from past cutting fires.

Some irregular multistoried stands have a light overory over groups and/or patches of immature trees rangg from reproduction to small poles that cover large eas that can be treated as stands. These are converted removing the scattered overstory and thinning and nprovement cutting in the understory to create a more niform diameter distribution (fig. 12).

Irregular multistoried stands should be converted to en-aged structure with a minimum impact on growg stock. The time needed for conversion depends upon and conditions; but in most stands it is likely to require e rest of the rotation. Shelterwood or other even-aged itting methods would be used to maintain the stand ructure.

To convert irregular multistoried stands composed of mosaic of even-aged groups and/or patches with trees the smaller and intermediate size classes to unevenged stands, maintain the integrity of the groups and subdivide the patches to create groups of about 2 acres or less in area (fig. 14). These groups may contain trees of different size classes. Groups containing trees of about the same size are treated to create a range of size classes. Some groups are heavily thinned, others lightly thinned, and in still others thinning is deferred. Trees in the heavily thinned groups grow faster and reach larger size earlier, whereas trees in the lightly thinned and unthinned groups grow more slowly and remain in the smaller size classes. Thinning to intermediate densities could create other size class groups. Improvement cutting usually is needed with thinning to remove diseased and dying trees.

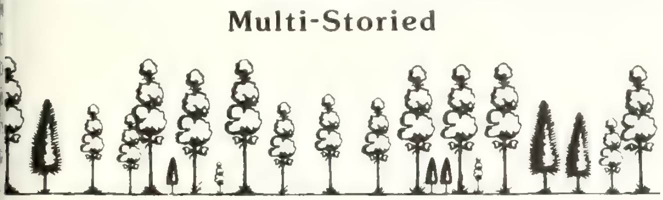
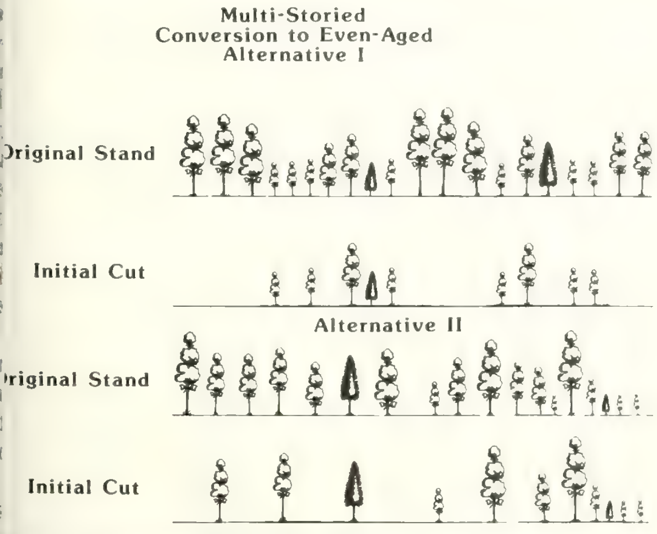


Figure 11.—Multistoried ponderosa pine stand.



igure 12.—Sequence of entries to convert multistoried ponderosa pine to even-aged stands.

Figure 13.—Dense patches of ponderosa pine in the Front Range should be thinned to improve productivity and appearance.

Irregular stands with larger trees also can be treated to create a range of size classes (fig. 14). Those groups composed of the largest and most defective trees are cut first to create a new small size class when regeneration becomes established in the openings. Other groups receive an intermediate cut, while other groups are left uncut to create different size classes. Variations of existing stand conditions are the basis for cutting treatments.

Once stands have been created that are composed of groups of trees of different sizes, they can be further differentiated and maintained by individual-tree and/or group selection, as discussed in the section on Uneven-Aged Cutting Methods. Time required for conversion depends upon the original stand conditions.

Reserve stands.—The number of trees left standing after partial cutting is a major factor in attaining the objectives of intermediate and regeneration cuts. A numerical system for designating this stocking is needed. The site quality of most ponderosa pine lands in the Front Range is relatively poor (site index 40 to 60). Site index is measured in feet at base age 100 years. This means that stocking levels must be lower than other ponderosa pine forests. For even-aged stands and even-aged groups created by standard and group shelterwood in single- and two-storied stands, and the mosaic of groups, patches, and stands created in multistoried stands being converted to even-aged management, the recommended stocking level should range from GSLs 40 to 80.

Stand density after treatment, expressed as GSL, is the relationship between basal area and average stand diameter after cutting. A GSL is named by the basal area desired when average stand diameter is 10 inches. Basal areas increase with diameter until 10 inches is reached, and remain constant thereafter. The designation "growing stock level 40" indicates that basal area is to be 40 square feet when average stand diameter after cutting is ≥10 inches. How basal areas vary with GSL in stands of equal average diameter is shown in table 1. Marking crews may prefer to use average distance between trees rather than basal area as a guide to reserve stocking. Equivalent distance for the GSL and diameter combinations in table 1 and for larger diameters are given in table 2.

Stand density specifications described previously create an estimation problem when average diameter after cutting will be less than 10 inches. The basal area to be left is based on the unknown posttreatment average

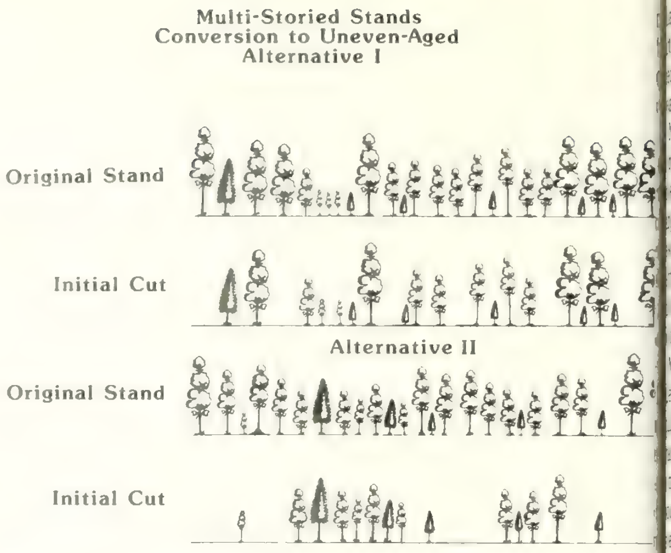


Figure 14.—Sequence of entries to convert multistoried ponderos pine to uneven-aged stands.

Table 1.—Basal areas (in square feet) after partial cutting in relation to average stand diameter (in inches), growing stock levels 40 to 100.

Average d.b.h. after cutting	Growing stock level			
	40	60	80	100
1.0	3.0	4.5	6.0	7.5
2.0	6.0	9.1	12.1	15.1
3.0	11.8	17.7	23.7	29.6
4.0	17.6	26.4	35.2	44.1
5.0	23.4	35.1	46.8	58.5
6.0	28.3	42.5	56.6	70.8
7.0	32.7	49.0	65.4	81.7
8.0	36.3	54.4	72.5	90.6
9.0	38.8	58.1	77.5	96.9
10.0 +	40.0	60.0	80.0	100.0

Table 2.—Average distance (in feet) between residual trees for different growing stock levels for ponderosa pine.

Average d.b.h. after cutting (inches	Growing stock level			
	40	60	80	100
1.0	8.9	7.3	6.3	5.6
2.0	12.5	10.2	8.9	7.9
3.0	13.4	11.0	9.5	8.5
4.0	14.7	12.0	10.4	9.3
5.0	15.9	13.0	11.3	10.1
6.0	17.4	14.2	12.3	11.0
7.0	18.9	15.4	13.3	11.9
8.0	20.5	16.7	14.5	13.0
9.0	22.3	18.2	15.8	14.1
10.0	24.4	19.9	17.2	15.4
11.0	26.8	21.9	19.0	17.0
12.0	29.2	23.9	20.7	18.5
13.0	31.7	25.9	22.4	20.0
14.0	34.1	27.9	24.1	21.6
15.0	36.6	29.8	25.8	23.1
16.0	39.0	31.8	27.6	24.7
17.0	41.4	33.8	29.3	26.2
18.0	43.9	35.8	31.0	27.7
19.0	46.3	37.8	32.7	29.3
20.0	48.7	39.8	34.5	30.8

iameter. Therefore, it is necessary to estimate diameter fter cutting and to determine the basal area goal. Exerience on treatment areas has shown that crews adapt adily to this procedure.

Markers must remember that level 40 does not mean reserve basal area of 40 square feet per acre unless verage diameter after cutting is 10 inches d.b.h. or rger. For smaller average diameters, level 40 means that ss, sometimes much less, than 40 square feet is to be ft. Also, reserve basal area is determined for each inividual group or stand treated, not as an average for idely dissimilar conditions.

Marking crews first should walk through each part of e treatment area to determine the type of cutting reuired and to obtain a mental picture of the group or and that should be left. Many patches are so small that marker in the middle of the area can see the patch oundaries. Minor adjustments in the estimate of verage diameter after cutting can be made, if necessary, s marking continues. Basal areas of leave trees should e checked periodically with a prism or other angle gage.

Most thinnings can be controlled by marking either the ees to be taken or those to be left. If cutting removes nly trees too small for posts or small poles, it may be ore efficient to use demonstration marking. In the latter ase, several patches of trees, each of different average ee diameter, should be marked to the residual basal reas desired. This can be done by flagging the reserve ees. Members of the thinning crews visit these sample reas as often as necessary for them to become familiar ith the spacings and densities desired for various verage diameters. Flagged patches remain unthinned ntil they are no longer needed as demonstrations Myers 1974).

Modifications for disease and insect problems.—In eneral, partial cutting should be limited to stands where e average dwarf mistletoe rating is 3 or less. Remove nly the percentage of basal area recommended for the and description, except that cutting of infected trees emphasized. In single-storied stands, trees in the inrmediate and lower crown classes should be removed efore dominants and codominants. In two-storied ands, as much of the first cut as possible should come om the second story, because those trees are likely to e more heavily infected than the top story. In single- nd two-storied stands, the final overstory removal can e delayed until the new reproduction is tall enough to rovide a forest aspect. To minimize infection of new eproduction, however, the time interval should not exeed 30 years after the regeneration cut when the average istletoe rating is 1, or 20 years when the rating is 2. he young stand should be sanitized at the final harvest Beatty 1982). In multistoried stands, the safest procedure an overwood removal coupled with improvement cutng and thinning to remove infected trees.

In old-growth stands with an average dwarf mistletoe ating greater than 3, any partial cutting or thinning is kely to intensify the infection. The safest procedure, erefore, is to either clearcut all of the trees and start new stand, or leave the stand uncut. Clearcut areas hould not be more than 150 feet from the seed source if regeneration is to be obtained from natural seeding, otherwise plan on planting the cleared area (Heidmann 1983). If the manager chooses to make a partial cut in a single- or two-storied stand for any reason, the initial harvest should be heavy enough to be a regeneration cut where there is no understory stand. Seed trees may be hard to find in heavily infected stands. All residual trees must be removed within 10 years after regeneration is established, and the young stand should be sanitized at that time (Beatty 1982). In two-storied stands with an acceptable stand of reproduction, the cut should be a simulated shelterwood to remove the overstory and a thinning or cleaning in the young stand to reduce infection.

In irregular multistoried stands, older groups and patches should be clearcut and a new stand started. Dense young and immature groups and patches can be left untreated if mortality is not excessive and adjacent stands require no special protection. They may be thinned if stand density reduction is needed to improve scenic or other values.

In areas of high tree values, such as recreational, administrative, and homesites, infected branches can be pruned from lightly infected trees; but heavily infected trees must be cut (Hawksworth 1961, Hawksworth et al. 1968, Lightle and Hawksworth 1973).

If mountain pine beetle is present in the stand at an endemic level or in adjacent stands in sufficient numbers to make successful attacks, and less than the recommended basal area to be removed in the first cut is in susceptible trees, any attacked trees and all of the most susceptible trees should be removed in the first cut. This will include most of the larger diameter trees in single- and two-storied stands, and most of the mature groups and patches and scattered overstory trees in multistoried stands. Dense stands of understory trees and young and immature groups and patches should be thinned. Provision should be made to salvage attacked trees. Moreover, the second cut should be made within 10 years.

If more than the recommended basal area to be removed in the first cut is in susceptible and/or attacked trees, the manager has three options: (1) remove all the trees in single- and two-storied stands and all mature groups and patches in multistoried stands, followed by thinning in dense young and stands, patches, or groups; (2) remove the recommended basal area in attacked and susceptible trees, thin the dense stands, patches, and groups of young immature trees (6 to 8 inches d.b.h.) to GSL 60 to 80, and accept the risk of future losses; or (3) leave the stand uncut. However, any benefits of thinning are not likely to be realized if the thinned area is small and surrounded by unthinned stands sustaining an attack (Stevens et al. 1975). If the stand is partially cut or left uncut, some trees in the smaller diameter classes will survive.

If a single-, two-, or multistoried stand is sustaining an infestation that is at epidemic levels or building up and the manager chooses to either partially cut or leave the stand uncut, there is a risk of an outbreak that could destroy most of the infested merchantable stand and spread to adjacent stands.

Cutting to save the residual stand.—In shelterwood cutting, protection of the residual stand from logging damage is a primary concern. The residual stand includes merchantable trees left after standard shelterwood and reproduction established after the seed cut in standard shelterwood, and reproduction established after each cut in group shelterwood. Before the final harvest is made with standard shelterwood and before each entry with group shelterwood, the manager must determine if there is an acceptable stand of reproduction. Furthermore, the stand must be reevaluated after final harvest in standard shelterwood and after each entry with group shelterwood to determine the need for supplemental stocking. The same criteria used to evaluate advanced reproduction with a simulated shelterwood applies here.

Protection begins with a well-designed logging plan at the same time of the first cut. To minimize damage, the same protection measures for management with advanced reproduction apply here.

Slash disposal and seedbed preparation.—Some treatment of logging slash and unmerchantable material may be needed after each cut, especially if *Ips* populations are observed. Treatment should be confined to concentrations and that needed to reduce visual and insect impacts. Piling and burning slash may cause damage to the residual stand, and is expensive and time consuming. Spot burning usually is more effective if stands are open and slash accumulations are kept away from residual trees. Treatment in stands often can be limited to lopping and scattering, chipping along the roadway, and hand piling and burning to minimize damage, especially where utilization of small material for small posts and firewood removes much of the slash (fig. 15). In group shelterwood cutting, if there is not a manageable stand of advanced reproduction, dozers equipped with brush blades can be used to concentrate slash for burning in the openings. Piles should be kept small to reduce the amount of heat generated.

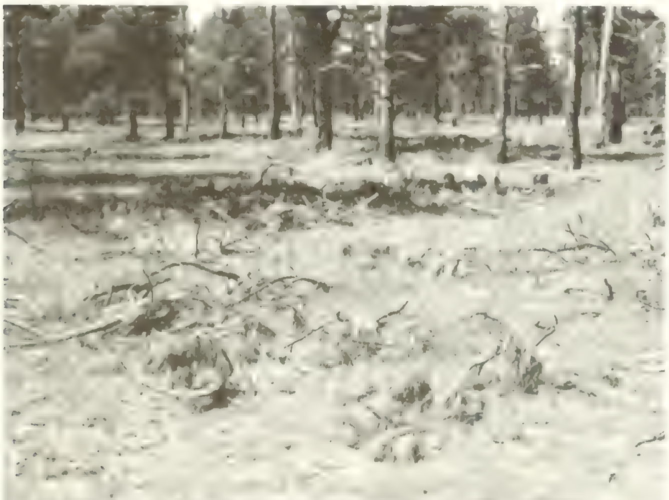


Figure 15.—Utilization of all usable material, including firewood, usually minimizes the need for slash disposal.

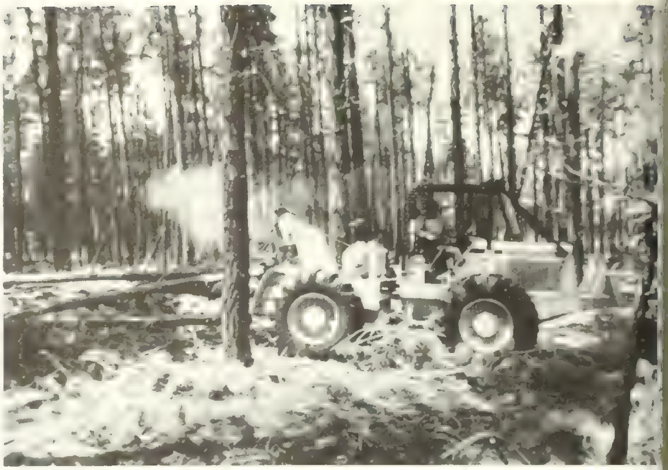


Figure 16.—Rubber tired skidders are too large to work well i seedbed preparation or slash disposal in partially cut stands.

On areas to be regenerated by new reproduction, a pa tial overstory canopy or trees standing around th margins of small openings provide two of the basi elements necessary for regeneration success—a see source within effective seeding distance and an enviro ment compatible with germination, initial survival, an seedling establishment. The manager must make su that the third element—a suitable seedbed—is provide after the regeneration cut where standard shelterwoo cutting is used and after each cut where group shelte wood or cuttings to convert irregular stand structure to managed stands is used.[2] Until special equipment developed, seedbed preparation, as well as slash disposa will pose problems. The equipment available is too larg to work well around standing trees (fig. 16). Small dozer other machines equipped with brush blades, or sma crawler tractors pulling a toothed disk equipped with hydraulic lift will have to be used; but they must be clos ly supervised to minimize damage to the residual stan

UNEVEN-AGED CUTTING METHODS

Single- and two-storied ponderosa pine stands are be maintained under even-aged cutting methods, preferab some form of shelterwood. However, multistoried stan frequently are uneven- to broad-aged by even-age groups and patches, or have diameter distributions mo closely associated with uneven-aged stands. Moreove uneven-aged management may be more compatible desirable for some management objectives or resour needs. For example, the impact on the forest should as light as possible in areas of steep topography an erosive soils or where management goals inclu maintenance of continuous forest canopy. Uneven-age management may be more appropriate for these cond tions and objectives.

Uneven-aged management includes cultural trea ments, thinnings, and harvesting necessary to mainta ontinuous high forest cover, provide for regeneration f desirable species, either continuously or at each arvest, and provide for controlled growth and development of trees through the range of size classes needed r sustained yield of forest products. Managed uneven-ged stands are characterized by trees of many sizes in-rmingled singly or in groups. Cutting methods do not roduce stands of the same age that are large enough be recognized as a stand. Forests are subdivided into cognizable units that can be located on the ground on e basis of timber type, site, logging requirements, etc., ther than acreage in stand-age classes. Growing stock regulated by setting: (1) a residual stocking goal, in rms of basal area or volume, that must be maintained provide adequate growth and yield, (2) a diameter istribution goal that will provide for regeneration, rowth, and development of replacement trees, and (3) maximum tree size goal. In addition, a decision must e made on how to handle small trees. Both individual-ee selection and group selection cutting methods will e considered in stands with irregular to all-aged struc-re (Alexander and Edminster 1977a, 1977b).

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[2] *Discussion of the silvical requirements and cultural practic necessary for successful ponderosa pine regeneration in the Fro Range is beyond the scope of this paper. For this information, se Schubert (1974).*

Individual-Tree Selection Cutting

This regeneration cutting method harvests trees in everal or all diameter classes on an individual basis. tands regenerate continuously. The ultimate objective to provide a stand with trees of different sizes and age asses intermingled on the same site (USDA Forest Serv-e 1983). Choice of trees to be cut depends on their haracteristics and relationship to stand structure goals t up to regulate the cut. This cutting method provides aximum flexibility in choosing trees to cut or leave and appropriate only in uniformly spaced stands with ir-egular to all-aged structure. However, because of onderosa pine's silvical characteristics, individual-tree election cutting is not recommended in pure stands. In ixed ponderosa pine—Douglas-fir stands, individual-ee selection can be used; but few pines are likely to be tablished after initial cutting.

Group Selection Cutting

This regeneration cutting method harvests trees in oups, ranging from a fraction of an acre up to about acres (USDA Forest Service 1983). It is similar to a oup shelterwood except in the way the growing stock regulated. The area cut is smaller than the minimum asible for a single stand under even-aged management. rees are marked on an individual-tree basis; but em-asis is on group characteristics, which means trees ith high potential for future growth are removed along ith trees with low growth potential. Loss in flexibility partly offset by the opportunity to uniformly release tablished regeneration and reduce future logging amage. When groups are composed of only a few trees, e method can be used together with individual-tree lection cutting in mixed stands. This cutting method most appropriate in irregular to broad-aged mixed or pure multistoried ponderosa pine stands that are clumpy, groupy, or patchy. However, it can be used in uniformly spaced stands with the size, shape, and arrangement of openings based on factors other than the natural stand conditions (Alexander and Edminster 1977a, 1977b).

Stand Structure Goals

Control of Stocking

The first step in applying a selection cut to a ponderosa pine stand is to determine the residual stocking level to be retained. Because total stand growth for many species under uneven-aged management does not differ greatly over the range of stocking levels likely to be management goals, stocking levels set near the lower limit, where no growth is lost, concentrate increment on fewest stems. This reduces time required to grow individual trees to a specific size, and requires a minimum investment in growing stock (Alexander and Edminster 1977b).

The residual stocking level with the best growth potential and most desirable appearance in pure or mixed ponderosa pine stands varies with species composition, management objectives, productivity, diameter distribution, etc. In unregulated old-growth ponderosa pine stands with irregular structure, stocking usually varies from 40 to 110 square feet of basal area per acre in trees in the 4-inch and larger diameter classes. Basal areas above 90 to 100 square feet per acre probably represent overstocking. While no guidelines are available for uneven-aged stands, residual stocking levels of GSL 40 to GSL 80 are suggested for managed even-aged stands, with the low site quality normally associated with ponderosa pine in the Front Range (Alexander and Edminster 1980). These levels should be useful in estimating initial residual stocking goals in terms of square feet of basal area per acre for that part of the stand that eventually will be regulated under uneven-aged management (Alexander and Edminster 1977b).

While these general recommendations are probably adequate to start with, use of yield tables for even-aged stands in setting stocking goals for uneven-aged stands assumes there is little difference between the growing stock of the two other than a redistribution of age classes over a smaller area (Bond 1952). This may be true when stands without a manageable understory of advanced growth are harvested by a group selection method. The result is likely to be a series of small, even-aged groups represented in the same proportion as a series of age classes in even-aged management. If advanced growth of smaller trees has become established under a canopy of larger trees, however, a different structure may develop with either individual-tree or group selection methods. Growing space occupied by each age or size class is being shared (Reynolds 1954). Assuming that damage to understory trees resulting from removal of part of the overstory trees can be minimized, advanced growth will successfully establish a series of age classes on some areas. In this situation, more trees of a larger size can be grown per acre than with a balanced even-aged growing stock (Bourne 1951, Meyer et al. 1961).

Nevertheless, without better information, the residual stocking goals set for even-aged management are the best criteria available.

Maximum Tree Size

The second item of information needed is the maximum diameter of trees to be left after cutting. In old-growth ponderosa pine stands with irregular spacing, in the Front Range, maximum diameter usually varies from 16 to 26 inches d.b.h., depending on stand density, site quality, species composition, etc. Examination of plot inventory information from unmanaged stands with irregular stand structure suggests that a diameter of 16 inches can be attained within the time period generally considered reasonable under the narrow range of site quality (SI 40–60) found in the Front Range and stocking levels likely to be management goals (GSL 40–80). In the absence of any information on growth rates in uneven-aged stands or rates of return for specific diameter stocking classes, a 16-inch maximum diameter seems a reasonable first approximation to set for timber production on lands of average site quality. Trees of larger diameter with a lower rate of return on investment may be appropriate for multiple-use reasons (Alexander and Edminster 1977b).

Control of Diameter Distribution

Control over distribution of tree diameters also is necessary to regulate yields under uneven-aged management. This most important step is accomplished by establishing the desired number of trees or basal area for each diameter class.

When used with flexibility, the quotient q between number of trees in successive diameter classes is a widely accepted means of calculating diameter distributions in uneven-aged stands (Meyer 1952). Values of q ranging between 1.3 and 2.0 (for 2-inch diameter classes) have been recommended for various situations. The lower the q, the smaller is the difference in number of trees between diameter classes. Stands maintained at a small q have a higher proportion of available growing stock i larger trees, for any residual stocking level, but may require periodic removal of the largest number of sma trees in the diameter class when unregulated growin stock crosses the threshold into the proportion of th stand to be regulated (Alexander and Edminster 1977b

Consider, for example, differences in the number o small and large trees maintained at a q level of 1.1, 1.3 and 1.5 in stands with the same residual basal area (6 square feet) (table 3). At all stocking levels considere appropriate for future management goals, many sma trees would have to be cut under lower q levels at th threshold diameter class (in this example the 4-inc class). Fewer larger trees would be retained under highe q levels.

In the absence of any experience, data, or good growt and yield information, the best estimate of numbers o trees to leave by diameter classes is to use the lowest value that is reasonable in terms of existing market stand conditions, and funds available for cultural worl Examination of plot data from a wide range of irregularl stocked old-growth ponderosa pine stands indicates th pretreatment distributions are likely to range betwee 1.2 and 1.5 for 2-inch classes. As a general recomme dation, q levels between 1.2 and 1.4 appear to be reaso able initial goals for the first entry into unmanage stands.

How to Determine Residual Stand Structure

Once goals for residual stocking, maximum tre diameter, and q levels have been selected, the specif structure for a stand can be calculated, provided th data are available to construct a stand table (Alexand and Edminster 1977b).

An existing old-growth ponderosa pine stand on th Manitou Experimental Forest in Colorado was select to illustrate the procedure. The actual inventory data f the stand is shown in columns 1, 2, and 3 of table 4. residual basal area of 60 square feet per acre in trees inches d.b.h. and larger has been chosen. A maximu tree diameter of 16 inches d.b.h. was chosen, becau it also appears to be a realistic goal to be attained in

Table 3.—Residual stand structures for 60 square feet of basal area (BA) and maximum tree diameter of 16 inches d.b.h. for various q values.

	q = 1.1		q = 1.3		q = 1.5	
class	No. of trees	BA (ft.^{2})	No. of trees	BA (ft.^{2})	No. of trees	BA (ft.^{2})
4	20.28	1.77	38.83	3.39	63.00	5.50
6	18.59	3.65	29.85	5.86	41.93	8.23
8	16.72	5.84	22.97	8.02	28.01	9.78
10	15.29	8.34	17.64	9.62	18.66	10.18
12	13.81	10.85	13.58	10.67	12.45	9.78
14	12.59	13.46	10.45	11.17	8.29	8.86
16	11.50	16.06	8.04	11.23	5.52	7.71
Total	108.78	59.97	141.76	59.96	177.85	60.04

sonable period of time. Finally, a q of 1.4 was chosen, cause it approximates the q in the natural stand and s not require removal of many small trees. A lower ay be feasible; but it would require heavy cutting in er diameter classes.

o determine the residual stand goal, the value of the dual density parameter k corresponding to a basal a of 60 square feet must be calculated. Values needed this computation with a q of 1.4 are given in column f table 5. The value of k is computed as

$$k = \frac{60.0}{0.62428 - 0.01558} = 98.57072$$

ere 60.0 is the desired basal area per acre, 0.62428 e table value for the desired maximum tree diameter s of 16 inches, and 0.01558 is the table value for the ch class. Note that the value for the 2-inch class is tracted from the 16-inch class value, because trees aller than the 4-inch class are not considered in the nagement guidelines. Desired residual number of trees in each diameter class (column 4 of table 4) can be directly calculated by multiplying the proper diameter class values given in column 5 of table 6 by the value of k. The desired residual basal area in each diameter class (column 5 of table 4) can be calculated by multiplying the residual number of trees in each diameter class by the tree basal area.

Comparing actual and desired diameter distributions shows where deficits and surpluses occur (fig. 17). To bring this stand under management, the number of trees should be allowed to increase in the diameter classes that are below the idealized stocking curve, with cutting limited to those diameter classes with surplus trees. As a guide, enough trees should be left above the curve in surplus diameter classes to balance the deficit in trees in diameter classes below the curve. In this example, there were no deficits. All surplus trees were cut in the 4- to 16-inch diameter classes. The final stand structure is shown in fig. 18 and columns 6 and 7 of table 4. Columns 8 and 9 show the trees and basal area removed.

Table 4.—Actual stand conditions and management goals for a ponderosa pine stand. All data are on a per acre basis—stand goals q = 1.4, residual basal area 60 square feet, maximum tree diameter of 16 inches d.b.h.

Diameter Class	Actual stand		Residual stand goal		Final stand		Cut	
(1)	Trees (2)	BA (3)	Trees (4)	BA (5)	Trees (6)	BA (7)	Trees (8)	BA (9)
4	58	5.06	50.29	4.39	50	4.36	8	0.70
6	41	8.05	35.92	7.05	36	7.07	5	0.98
8	42	14.66	25.66	8.96	26	9.08	16	5.58
10	19	10.36	18.33	10.00	18	9.82	1	0.54
12	18	14.13	13.09	10.28	13	10.21	5	3.92
14	19	20.31	9.35	10.00	9	9.62	10	10.69
16	14	19.55	6.68	9.33	7	9.77	7	9.78
18	1	1.77	0	0	0	0	1	1.77
20	1	2.18	0	0	0	0	1	2.18
22	2	5.28	0	0	0	0	2	5.28
Total	215	101.35	159.32	60.01	159	59.93	56	41.42

Table 5.—Values needed to compute k for different q ratios and diameter ranges using basal area as the density measure (Alexander and Edminster 1977b).

2-inch diameter classes (1)	q ratio 1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)
2	0.01983	0.01818	0.01678	0.01558	0.01454
4	.09196	.07878	.06842	.06011	.05333
6	.23948	.19241	.15779	.13166	.11151
8	.47790	.36075	.28001	.22253	.18046
10	.81656	.57994	.42691	.32394	.25228
12	1.25990	.84297	.58963	.42825	.32124
14	1.80848	1.14132	.75999	.52966	.38380
16	2.45985	1.46605	.93116	.62428	.43828
18	3.20930	1.80854	1.09780	.70981	.48425
20	4.05043	2.16089	1.25606	.78523	.52209
22	4.97568	2.51618	1.40336	.85042	.55251
24	5.97669	2.86853	1.53820	.90583	.57682

Table 6.—Values needed to compute desired number of residual trees for different q ratios (Alexander and Edminster 1977b).

2-inch diameter classes D_i (1)	q ratio 1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)
2	0.909091	0.833333	0.769231	0.714286	0.666667
4	.826446	.694444	.591716	.510204	.444444
6	.751315	.578704	.455166	.364431	.296296
8	.683013	.482253	.350128	.260308	.197531
10	.620921	.401878	.269329	.185934	.131687
12	.564474	.334898	.207176	.132810	.087791
14	.513158	.279082	.159366	.094865	.058528
16	.466507	.232568	.122589	.067760	.039018
18	.424098	.193807	.094300	.048400	.026012
20	.385543	.161506	.072538	.034572	.017342
22	.350494	.134588	.055799	.024694	.011561
24	.318631	.112157	.042922	.017639	.007707

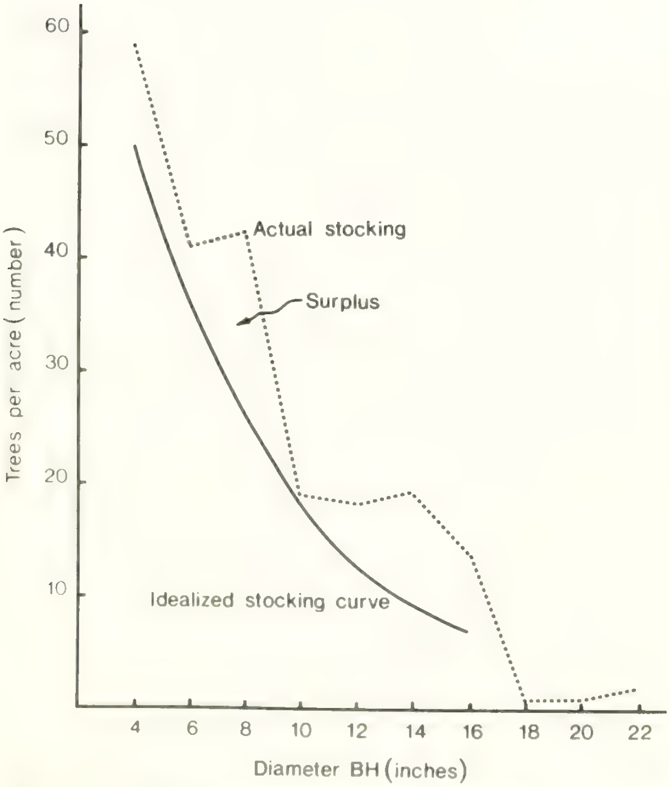

Figure 17.—Actual stocking curve from data collected on the Manitou Experimental Forest and the idealized stocking curve based on stand structure goals.

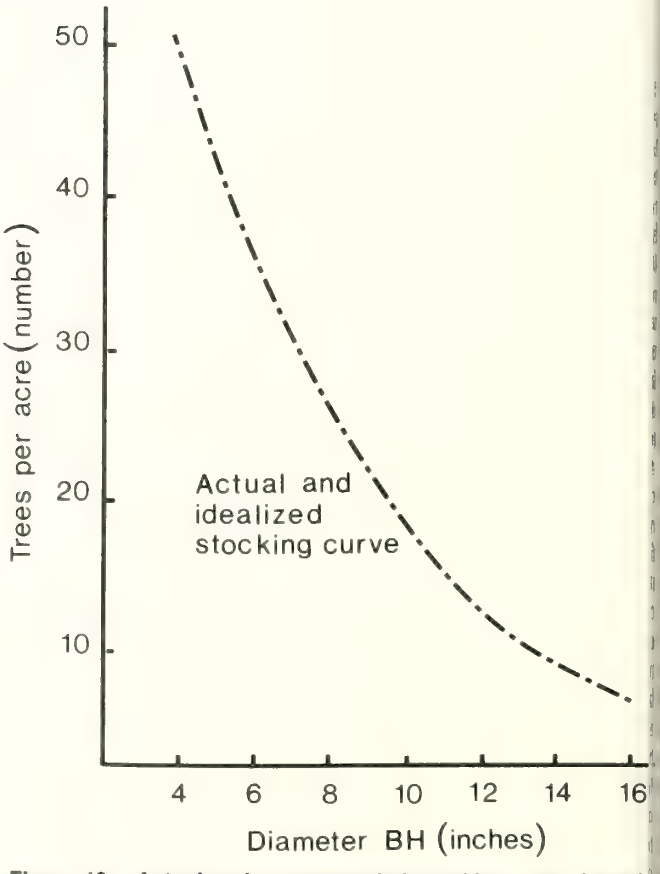

Figure 18.—Actual and recommended stocking curve based n stand structure goals are the same in this example.

How to Handle Small Trees

he threshold diameter class also must be determined. culations often are made down to the 4-inch diameter ss by 2-inch classes, because often there are small trees ow minimum merchantable diameter, especially in ked stands. They compete with larger stems for grow- space. More important, these trees provide ingrowth o merchantable size classes needed to practice selec- n silviculture.

lthough small trees should not be ignored in inven- y and record keeping, it may be neither desirable nor ssible to regulate the number of them. In ponderosa e forests in the central Rocky Mountains, minimum rchantable diameter is usually 5 to 8 inches. Regula- n of the number of trees below this size requires an estment in silvicultural work that may not be recap- ed under current market conditions. However, if trees ow minimum merchantable size are left unregulated, tting must always be heavy in the threshold diameter sses to bring ingrowth trees down to the desired mber. It also means that more growing space is re- ired for small trees than called for by the idealized nd structure. Moreover, the higher the threshold meter class, the greater is the proportion of the stand t is unregulated. More growing space is occupied by es of low value that will be cut as soon as they cross threshold diameter (Alexander and Edminster 77b).

Marking Trees

fter residual stocking goals have been calculated and ecision has been made on how to handle small trees, stand must be marked. Marking is difficult, because marker must designate cut or leave trees, usually with e pass through the stand, based on limited inventory ta. At the same time, the marker must apply good viculture and be aware of economic limitations. As a neral rule, good silvicultural prescriptions are more portant than strict adherence to structural goals, ecially in unregulated stands being cut for the first e. However, marking without a structural goal—or scribing structural goals than cannot be attained or plied—defeats the objective of regulation.

ecause marking for individual-tree selection cutting more complex than for other systems, some formal ntrol procedure is necessary. Often only an estimate the initial desired residual diameter distribution is eded. With these estimates, basal areas and number trees to be removed per acre by diameter classes can determined. Control is maintained by a process of suc- ssive checks of residual versus the goal. For example, markers should systematically make prism estimates the residual stand after marking, recording trees by or 4-inch classes on a standard cumulative tally sheet. riodically, they should convert the prism tally to trees r acre, and compare their average prism estimate to structural goal. Markers must then adjust to any ious deviation from the structural goal, such as too avy marking in some diameter classes and too light in others. Their next check will determine if progress is being made or if further changes are needed. By this process, the average residual stand should come fairly close to the structural goal (Alexander and Edminster 1977b).

Marking under group selection cutting is less complex than under individual-tree selection; but control over the diameter distribution is also necessary. The objective is to create a series of openings over time and space with each opening containing a given diameter class.

It is not likely that unregulated stands will be brought under management with one entry or even a series of entries. It is more likely that limitations imposed by stand conditions, dwarf mistletoe, and mountain pine beetle susceptibility will result in either over- or undercutting, at least in the first entry.

Recommendations for Selection Cutting

These are based on experience, and dwarf mistletoe and mountain pine beetle susceptibility. Selection cutting methods are appropriate for multistoried pure or mixed stands with irregular or uneven-age stand structure. Individual-tree selection should be confined to mixed stands with uniform spacing. Group selection can be used in stands with either clumpy, groupy, or patchy spacing, or uniform spacing. Selection cutting methods are not appropriate in stands sustaining a mountain pine beetle attack or in stands where enough beetles are present within the stand or adjacent stands to make successful attacks, or in stands where the dwarf mistletoe rating is 3 or more.

Stand Structure Goals, Cutting Treatments, and Reentry Schedules

The stocking goal for the initial entry should be set so that not more than 30% to 40% of the stand basal area is removed. With individual-tree selection, the cut should be distributed over the entire area. With group selection, not more than one-third of the area should be cut. If the stand is groupy, clumpy, or patchy, the size of opening should be determined by the size of the group, clump, or patch. If the stand is uniformly spaced, the size of the opening should not exceed 2 to 3 times tree height. Keep the openings small.

Maximum tree diameter should not exceed that attained in the unmanaged stand. The diameter distribution should be set at a "q" value that most closely approximates the natural "q" value of the stand. However, remember that low q values require cutting a larger number of trees at the threshold diameter class and high q values retain few larger trees. The threshold value should be set at the smallest diameter class practical. All trees below the threshold diameter class are unregulated. Some diameter classes will have a surplus of trees and some will have a deficit. Surpluses and deficits must be balanced if the residual basal area is to maintained. Subsequent entries should be made at 10- to 30-year intervals. While it would be desirable to enter the stand at 10-year intervals, it is not likely that growth rates will permit this in most instances. Some diameter classes will not be completely represented; therefore, volumes available for cutting may not warrant a 10-year reentry until a controlled diameter distribution is attained.

Protecting the Residual Stand

Protection of the residual stand is critical with individual-tree selection cutting because of frequent entries into the stand once a controlled diameter distribution is attained. Damage can result from felling, skidding, and slash disposal.

Felling damage can be reduced by using group selection and dropping trees in the openings or marking a small clump of trees where felling one large tree will damage several adjacent trees. Procedures outlined for protecting the residual and disposing of slash for shelterwood cutting should be followed here.

COST OF SALE ADMINISTRATION AND LOGGING

One of the most important factors affecting the administrative cost of selling timber is the number of entries needed for harvesting. Simulated shelterwood requires only one entry. Standard shelterwood requires two to three entries. Group shelterwood and individual-tree and group selection require from three to six entries, depending upon cutting cycles. In managed stands, even-aged systems require a minimum of two additional entries for thinnings; but the number of entries under uneven-aged systems would not change.

Costs of sale layout, marking, and sale contract administration are lower for simulated and group shelterwood, group selection (when groups are near the maximum size), and the final cut of standard shelterwood than for individual-tree selection, and the intermediate, preparatory, and seed cuts of standard shelterwood. Costs are reduced, because only cutting boundaries are marked, and no time is spent deciding which trees to cut or leave. Sale administration is easier, because there are no residual trees to protect and no opportunity to cut unmarked trees. However, reproduction must be protected at the time of final cut under any shelterwood system.

Timber harvesting in the Front Range may require road construction. Shelterwood is the most economical method in terms of volume removed per unit of road; individual-tree selection is the most expensive. Development of a transportation system to manage forests is a costly front-end investment that will require funding in addition to the value of stumpage at the time of first entry. Once the transportation system has been constructed, road costs should be independent of cutting method.

The maximum volume per acre is usually produced in the final cut of standard shelterwood or simulated shelterwood; but each cutting method requires maximum concern for protection of the residual stand. The first entry of a standard shelterwood is intermediate in volume production per acre, requires moderate concern for the residual stand, and places some constraints selection of equipment. Individual-tree selection requi maximum concern for the residual stand. Group sel tion and group shelterwood require slightly less if size of the opening is near maximum. Under unev aged and group shelterwood cutting methods, volur per entry are intermediate, size-class diversity of pr ucts harvested is minimum, and a choice of logg equipment is limited.

MULTIPLE-USE SILVICULTURE

POTENTIAL TIMBER YIELDS

Highest potential timber yields can be realized un a two-cut shelterwood option, provided that the fi harvest with a shelterwood is made within 5 years a regeneration is established. Comparable growth rates be achieved with group shelterwood and group select only if the openings are near the maximum size (2 ac Total yields will be less under a three-cut shelterwo Under simulated shelterwood, yield increases resul from reduction in rotation length may be offset by slower growth of trees in the replacement stand. Yi will be less under individual-tree and group selectio situations where very small openings are cut.

SOIL WATER RESOURCES

Water Yield

In ponderosa pine forests in the Front Range, the portion of water yielded to precipitation is low, beca about two-thirds of the precipitation falls as rain du the growing season, when evapotranspiration losses high, and winter snowpack is intermittent. Consequ ly, of the 15 to 20 inches of precipitation, only about to 25% (2–5 inches) becomes streamflow (Gary 19 Although water yields are small compared to hi elevation forests, they are important. The larges creases in water yield would occur if trees were vested in small clearcut patches about 5 tree heigh diameter interspersed so that they are about 5 to 8 heights apart. The increase in runoff is largely a re of reduced interception and evapotranspiration; b also may be affected by redistribution of precipita However, clearcutting is not a recommended optic ponderosa pine in the Front Range because of c resource requirements, except in stands with seriou sect and disease problems.

Group shelterwood and group selection cutting rec mended for patchy and groupy uneven-aged stands be nearly as favorable for increasing streamflow as p clearcutting, if openings are near the maximum si 2 acres. In the low precipitation-high energy env ment of the Front Range, partial cutting treatments as individual-tree selection and shelterwood are not ly to change water yields from that available from cut forests.

Soil Erosion

oil and site conditions are not the same in all nderosa pine forests; but many of them grow on either idual soils derived from granitic schists or alluvium s derived from granitic rock. These soils are generally nsidered to be naturally erosive. When protective plant ver is removed and soils distributed by roadbuilding, ging, and fire, natural erosion processes are ac- erated (Gary 1975). Careful location, construction, and intenance of skid and haul roads associated with any ting method should not cause a lasting increase in ero- n. For example, Dortignac and Love (1966) concluded t when organic materials on the ground exceeded 2 ns per acre, and less than 30% of the treated area was turbed, erosion losses will usually be less than 500 unds per inch of runoff.

Nutrient Loss and Stream Water Temperature Changes

Removal of logs in timber harvest represents a small d temporary net loss of nutrients, because only a minor oportion of the nutrients taken up by a tree is stored the bole. Cutting that removes all, or most all trees, ults in a greater immediate loss than partial cutting; t over a rotation, the losses would balance out because more frequent cuts under the partial cutting methods. rthermore, nutrients lost after cutting all, or most all es, should be replaced in 10 to 20 years through tural cycling as regeneration becomes established.

ncreases in stream temperature can be avoided, even th clearcutting, by retaining a border of trees along eam channels. Actually, clearcutting to the stream annel and subsequent warming of the water may be vantageous where streams are frequently small and o cold to support adequate food supplies for fish.

ILDLIFE AND RANGE RESOURCES

Game Habitat

Old-growth ponderosa pine stands provide habitat for variety of game animals. Group shelterwood and group election provide the largest increases in quantity and uality of forage for big game; but use often is limited the amount of cover available for hiding, resting, and minating.

Dispersed openings 2 and 5 acres in size are used more deer and elk than smaller or larger openings or un- it timber. Very small openings provide little diversity; me animals usually use only the edges around large penings. As trees grow to seedling and sapling size, rage production in cleared areas diminishes (Currie 975), but cover increases until it reaches maximum in ature stands.

Standard shelterwood cutting provides less forage for g game than cutting methods that create openings; the duction is in proportion to the density of the overstory d length of time it is retained. Shelterwood cutting also provides less cover than an uncut forest. Individual-tree selection provides forage and cover comparable to uncut forests, thereby maintaining one type of habitat at the expense of creating diversity.

Nongame Habitat

Information is limited on the relationship of cutting methods in ponderosa pine forests in Front Range to specific nongame habitat requirements; but it is possible to estimate probable effects. Group shelterwood and group selection that create small, dispersed openings provide a wide range of habitats attractive to some birds and small mammals by increasing the amount of nontree vegetation—at least initially—and length of edge between dissimilar vegetation types.

Standard shelterwood cutting provides a variety of habitats attractive to species that forage in stands with widely spaced trees but not to those that require closed forests or fully open plant communities. Under this method, trees are still available for nesting, denning, and feeding until the final harvest, when consideration should be given to retaining some of the limby live trees and snags and live trees with cavities. For example, large ponderosa pines are preferred for food and cover by Abert's squirrels (Keith 1965). Conditions are improved when the rather uniform spacings that usually result from partial cuttings are interrupted by occasional clumps of three or four closely spaced large trees. Maintenance of squirrel populations, therefore, requires avoiding conversion of large areas to seedling and sapling stands. Development of scattered, young stands of reasonable area creates no special problems.

Harvesting old-growth timber can be devasting to species like the flammulated owl that nest or den in snags and in cavities of live trees, feed largely on insects, and require solitary habitats normally associated with large areas of old-growth. Most nongame species have a minimum habitat size below which they can not exist. Small patches of varying ages and structure and all-aged stands may reduce the number of species. Individual-tree selection provides the least horizontal diversity and favors species attracted to uncut forests or that require vertical diversity. However, snags and live tree cavities can be retained under any silvicultural system.

The low-vigor, large-limbed, or dead trees used by wildlife would be prime choices for removal if special effort is not made to save them. So few trees per acre are involved in this type of habitat maintenance that their preservation has a negligible adverse effect on the appearance of the forest and other values. Regardless of the silvicultural methods applied, these trees should remain untouched as long as they are useful to wildlife.

Lifestock Grazing

Historically, ponderosa pine and associated bunchgrass ranges have been important livestock producing areas in the Front Range. The pine and bunchgrass type is a complex of plant communities. Its one apparent and common characteristic is open grassland parks interspersed with forested areas. Natural forested areas may be open with extensive herbaceous understory vegetation or closed with little or no understory vegetation (Currie 1975). Forage production and changes in species composition and palatability vary considerably, depending upon plant community and successional stage. Forage production increases most when group shelterwood and group selection openings are cut in dense stands. The increase in forage production in these openings persists for 10 to 20 years before competition from tree reproduction begins to reduce understory vigor and composition. It can be maintained only by frequent intermediate cuttings to keep density low. Forage production after shelterwood and individual-tree selection cutting is in relation to the amount of overstory retained and time between entries in the stand.

RECREATION AND ESTHETICS

Ponderosa pine forests in the Front Range provide a variety of recreation opportunities. Users who hike, backpack, or view scenery are generally attracted to forests whose natural appearance is little altered by human activities (Calvin 1972). In contrast, hunters have best success where human activities are apparent—timber sales and other areas readily accessible by roads. Fishing is mostly done in accessible lakes, reservoirs, and streams. Generally, most camping opportunities are at both publicly and privately developed sites served by roads. Most scenery viewing is by automobile on developed roads. Finally, some forms of recreation, such as mountain home development, require drastic modification of the natural forest landscape.

Cutting openings has the greatest visual impact, and individual-tree selection has the least. However, variety typical of forests whose texture is broken by natural openings is preferred to the monotony of unbroken forest landscapes (Kaplan 1973).

To enhance amenity values, cutting openings to harvest timber and improve wildlife habitat should be a repetition of natural shapes visually tied together to create a balanced and unified pattern that will complement the landscape (Barnes 1971). This is especially important for openings in the middleground and background seen from a distance. Standard or simulated shelterwood or individual-tree selection can be used to retain a landscape in foregrounds.

Individual-tree selection, group selection, and group shelterwood cutting are appropriate in high-use recreation areas, travel influence zones, scenic-view areas, and subdivision developments where permanent forest cover is desired. The visual impact of logging can be minimized by cleanup of debris and slash and by careful location of roads.

COMPARISON OF CUTTING METHODS

No silvicultural system or cutting method (including no cutting at all) meets all resource needs. Group shelterwood and group selection that cut small openings pr vides maximum yields of timber at less costs, promot the largest increases in water production without serio reduction in quality, produces diversity of food supp and cover favored by many wildlife species, and necessary for the development of recreation sites a home subdivisions. Production and utilization livestock forage may be less than in larger openin however. Cutting openings can create adverse visual fects if no thought is given to the size and arrangeme of the openings; but it can also be used to create lar scape variety that will enhance amenity values.

Standard and simulated shelterwood cutting also p vide maximum timber yields over the same time int val, but at increased costs; they produce a wide ran of wildlife habitats, but with less forage than openin and less cover than uncut forests. Water yields are n increased over natural streamflow, however. Shelt wood cutting provides a partial retention of the for landscape, particularly when the overstory is retain for a long time.

Individual-tree selection cutting is not appropriate timber production in pure ponderosa pine stands, b could be used to meet other resource needs. Water yie are not greater than from uncut forests. Individual-tr selection cutting provides minimum horizontal diver ty in wildlife habitat, but favors species attracted to un forests. It also provides maximum partial retention of natural forest landscape. Group selection with very sm openings accomplishes about the same things individual-tree selection.

Not all resource needs can be met on a given site n is any one cutting method compatible with all uses. La managers must recognize the potential multiple-u values of each area, determine the primary and seco ary uses, and then select the management alternative t is most likely to enhance or protect these values wit the limits imposed by stand conditions and damag agents. On an individual site, some uses probably m be sacrificed or diminished to maintain the quantity a quality of others.

LITERATURE CITED

Alexander, Robert R., and Carleton B. Edminster. 197a. Regulation and control of cut under uneven-ag management. USDA Forest Service Research Pa RM–182, 7 p. Rocky Mountain Forest and Range x periment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 197b. Uneven-aged management of old-growth spruce forests: cutting methods and stand structure goals initial entry. USDA Forest Service Research Pa RM–186, 12 p. Rocky Mountain Forest and Range x periment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 19 0. Management of ponderosa pine in even-aged sta s in the Southwest. USDA Forest Service Resea h Paper RM–225, 11 p. Rocky Mountain Forest d Range Experiment Station, Fort Collins, Colo.

ker, Frederick S. 1949. A revised tolerance table. Jour-ıal of Forestry 47:179–181.

rnes, R. Lawrence. 1971. Patterned tree harvest pro-osed. Western Conservation Journal 28:44–47.

rrett, James W., Philip M. McDonald, Frank Ronco, r., and Russell A. Ryder. 1980. Interior ponderosa pine :37. p. 114–115. *In* F. A. Eyre, editor. Forest cover ypes of the United States and Canada. Society of merican Foresters, Washington, D.C.

atty, Jerome S. 1982. Southwestern dwarf mistletoe *Arceuthobium vaginatum* subsp. *Cryptopodium* Engelm.)) gill, in ponderosa pine. USDA Forest Serv-ce Integrated Pest Management Guide R–3 82–13, 2 p. Forest Pest Management State and Private orestry, Southwestern Region, Albuquerque, N. Mex.

nd, E. W. 1952. Growing stock differences in even-ıged and all-aged forests. Journal of Forestry 0:691–693.

urne, R. 1951. A fallacy in the theory of growing tock. Forestry 24:6–18.

lvin, J. S. 1972. An attempt at assessing preferences or natural landscapes. Environment and Behavior (4):447–470.

app, Earle. 1912. Silvicultural systems for western ellow pine. Society of American Foresters, Pro-eedings 7:168–176.

rrie, Pat O. 1975. Grazing management of ponderosa ine-bunchgrass ranges of the central Rocky Moun-ains: the status of our knowledge. USDA Forest Serv-ce Research Paper RM–159, 24 p. Rocky Mountain orest and Range Experiment Station, Fort Collins, olo.

rtignac, E. J., and L. D. Love. 1960. Relation of plant over to infiltration and erosion in ponderosa pine orests of Colorado. American Society of Agricultural Engineers Transactions 3:58–61.

rniss, R. L., and V. M. Carolin. 1977. Western forest insects. U.S. Department of Agriculture, Miscellaneous Publication 1339, 654 p. Washington, D.C.

ry, Howard L. 1975. Watershed management prob-ems and opportunities for the Colorado Front Range onderosa pine zone: the status of our knowledge. SDA Forest Service Research Paper RM–139, 32 p. Rocky Mountain Forest and Range Experiment Sta-ion, Fort Collins, Colo.

ry, Howard L. 1985. A summary of research at the Manitou Experimental Forest, Colorado. USDA Forest Service General Technical Report RM–116, 24 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

een, Allen W., and Duane D. Van Hooser. 1983. Forest resources of the Rocky Mountain states. USDA Forest Service Research Bulletin INT–33, 127 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

awksworth, Frank G. 1961. Dwarf mistletoe of ponderosa pine in the Southwest. U.S. Department of Agriculture Technical Bulletin 1246, 112 p. Washington, D.C.

Hawksworth, Frank G. 1977. The 6-class dwarf mistletoe rating system. USDA Forest Service General Technical Report RM–48, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hawksworth, Frank G, James L. Stewart, and Wilmer F. Bailey. 1968. You can save your pines from dwarf mistletoe. USDA Forest Service Research Paper RM–35, 20 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Heidmann, L. J. 1983. Silvicultural control of dwarf mistletoe in southwestern ponderosa pine. USDA Forest Service Research Note RM–433, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hepting, George H. 1971. Diseases of forest and shade trees of the United States. U.S. Department of Agriculture Handbook 386, 685 p. Washington, D.C.

Johnson, David W., Frank G. Hawksworth, and Laura M. Merrill. 1984. Ponderosa pine dwarf mistletoe loss assessment survey on national forest land in Colorado. USDA Forest Service Technical Report R–2–27, 13 p. Timber, Forest Pest, and Cooperative Forestry Management, Rocky Mountain Region, Denver, Colo.

Kaplan, R. 1973. Predictors of environmental preferences. Designers and "clients". p. 265–274. *In* W. F. E. Prieser, editor. Environmental Design Research. Proceedings of 4th International EDRA Conference. [Blacksburg, Va., April, 1973]. Dowden, Hutchinson, and Ross, Stroudsburg, Penn.

Keith, James O. 1965. The Abert squirrel and its dependence on ponderosa pine. Ecology 46:150–163.

Lightle, Paul C., and Frank G. Hawksworth. 1973. Control of dwarf mistletoe in heavily used ponderosa pine recreation forests: Grand Canyon, Arizona. USDA Forest Service Research Paper RM–106, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Lightle, Paul C., and Melvyn J. Weiss. 1974. Dwarf mistletoe of ponderosa pine in the Southwest. U.S. Department of Agriculture Forest Pest Leaflet 19, 8 p. Washington, D.C.

McCambridge, William F., and Galen C. Trostle. 1972. The mountain pine beetle. U.S. Department of Agriculture Forest Pest Leaflet 2, 6 p. Washington, D.C.

Meyer, H. A. 1952. Structure, growth, and drain in balanced uneven-aged forests. Journal of Forestry 50:85–92.

Meyer, H. A., A. D. Rechnagel, D. D. Stevenson, and R. A. Bartoo. 1961. Forest Management. 282 p. The Roland Press Company, New York, N.Y.

Myers, Clifford A. 1974. Multipurpose silviculture in ponderosa pine stands of the montane zone of central Colorado. USDA Forest Service Research Paper RM–132, 15 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Pearson, G. A. 1910. Reproduction of western yellow pine in the Southwest. U.S. Forest Service Circular 174, 16 p. Washington, D.C.

Peterson, R. S., and R. G. Shurtleff, Jr. 1965. Mycelium of limb rust fungi. American Journal of Botany 25: 519–525.

Reynolds, R. R. 1954. Growing stock in all-aged forests. Journal of Forestry 52:744–747.

Ronco, Frank, Jr., and Kenneth L. Ready. 1983. Southwestern ponderosa pine. p. 70–72. *In* Silvicultural systems for major forest types of the United States. R. E. Burns, technical compiler. U.S. Department of Agriculture, Forest Service, Handbook 445, 191 p. Washington, D.C.

Sartwell, Charles, R. F. Schmitz, W. J. Buckhorn. 1971. Pine engraver, *Ips pini*, in the western States. U.S. Department of Agriculture, Forest Service, Forest Pest Leaflet 122, 5 p. Washington, D.C.

Schubert, Gilbert H. 1974. Silviculture of southwestern ponderosa pine: the status of our knowledge. USDA Forest Service Research Paper RM–123, 71 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Stevens, Robert E., J. Wayne Brewer, and David
Leatherman. 1980. Insects associated with pondero
pine in Colorado. USDA Forest Service Gener
Technical Report RM–75, 42 p. Rocky Mounta
Forest and Range Experiment Station, Fort Collir
Colo.

Stevens, Robert E., Clifford A. Myers, William
McCambridge, George L. Downing, and John G. La
1975. Mountain pine beetle in Front Range pondero
pine: what it's doing and how to control it. USI
Forest Service General Technical Report RM–7, 3
Rocky Mountain Forest and Range Experiment S
tion, Fort Collins, Colo.

U.S. Department of Agriculture, Forest Service. 19
Silvicultural systems for the major forest types of t
United States. R. E. Burns, technical compiler. Ag
cultural Handbook No. 445, 191 p. Washington, D

Alexander, Robert R. 1986. Silvicultural systems and cutting methods for ponderosa pine forests in the Front Range of the central Rocky Mountains. USDA Forest Service General Technical Report RM–128, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting practices needed to convert old-growth and mixed ponderosa pine forests in the Front Range into managed stands for a variety of resource needs. Guidelines consider stand conditions, and insect and disease susceptibility. Cutting practices are designed to integrate maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing, with providing wood products.

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Alexander, Robert R. 1986. Silvicultural systems and cutting methods for ponderosa pine forests in the Front Range of the central Rocky Mountains. USDA Forest Service General Technical Report RM–128, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting practices needed to convert old-growth and mixed ponderosa pine forests in the Front Range into managed stands for a variety of resource needs. Guidelines consider stand conditions, and insect and disease susceptibility. Cutting practices are designed to integrate maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing, with providing wood products.

Keywords: Silvicultural systems, timber harvesting, *Pinus ponderosa*

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*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

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Diseases of Trees in the Great Plains

Jerry W. Riffle and Glenn W. Peterson

Technical Coordinators

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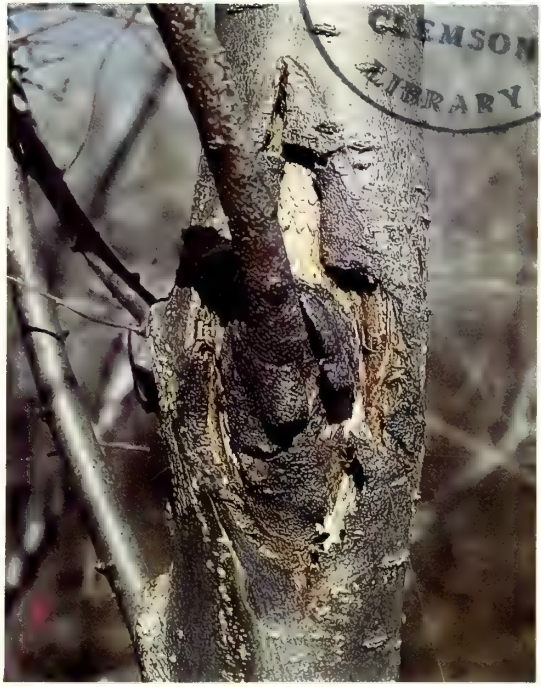

Riffle, Jerry W.; Peterson, Glenn W., tech. coords. Diseases of trees in the Great Plains. Gen. Tech. Rep. RM–129. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1986. 149 p.

Abstract

Hosts, distribution, symptoms and signs, disease cycle, and control measures are described for 46 hardwood and 15 conifer diseases. Diseases in which abiotic agents are contributory factors also are described. Color and black-and-white illustrations that stress diagnosis and control are provided. A glossary of technical terms and indexes to hosts, pathogens, and insect vectors also are included.

Keywords: Tree diseases, forest pathology, Great Plains, windbreaks

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SDA Forest Service
eneral Technical Report RM-129

June 1986

Diseases of Trees in the Great Plains

Technical Coordinators:

Jerry W. Riffle and Glenn W. Peterson
Rocky Mountain Forest and Range Experiment Station[1]

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[1] *Headquarters is in Fort Collins, in cooperation with Colorado State University; technical coordinators are plant pathologists at the Station's Research Unit at Lincoln, Nebraska, in cooperation with the University of Nebraska—Lincoln.*

Preface

This technical report provides a guide to assist arborists, land owners, pest management specialists, foresters, and plant pathologists in the diagnosis and control of tree diseases encountered in the Great Plains. It contains 64 articles on tree diseases prepared by 31 authors, and emphasizes disease situations as observed in the 10 states of the Great Plains.

The need for such a Handbook for the Great Plains has been recognized for some time.

During its 1980 meeting the Pest Management Task Force of the Forestry Committee, Great Plains Agricultural Council requested that the Forestry Committee "support the publication of a 'Tree Disease Handbook for the Great Plains', by the Task Force, and assist the Task Force in obtaining the necessary funding." The request was approved.

During the Task Force's 1981 meeting a working group was formed to prepare a prospectus for the Handbook. The working group members, Dr. Edward M. Sharon, Mr. James A. Walla, Dr. Mark O. Harrell, and Dr. Jerr W. Riffle, selected specific diseases for inclusion in th Handbook, selected potential authors for each article and determined the format for articles to emphasiz diagnosis, biology, damage, and control of diseases.

In 1982 the Pest Management Task Force agreed tha Dr. Riffle would serve as coordinator of the Handbook with Dr. Glenn Peterson as co-coordinator. Dr. Riffl contacted all potential contributors in May 1982, an their response was excellent; 31 persons agreed to autho or co-author articles on 64 diseases.

Funding for the publication of the Handbook wa resolved in 1985 when it was proposed that the Handbook be published as a General Technical Report by the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. This proposal was approved by the Executive Committee of the Forestry Committee of the Great Plains Agricultural Council.

Contents

Page
Authors and Their Affiliations iv
Acknowledgements vi
Introduction 1
Use and Safe Handling of Pesticides 3

HARDWOOD DISEASES
Foliage

1. Melampsora Leaf Rust of Cottonwood and Willow 4
Glenn W. Peterson and Robert W. Stack
2. Marssonina Leaf Spot of Cottonwood and Aspen 6
John E. Watkins and David S. Wysong
3. Septoria Leaf Spots of Cottonwood, Caragana, and Maple 8
Joseph M. Krupinsky and David W. Johnson
4. Phyllosticta Leaf Spots of Maple and Caragana 10
Robert L. James and David W. Johnson
5. Tar Spot of Maple 12
Edward M. Sharon and Jerry W. Riffle
6. Mycosphaerella Leaf Spots of Ash 14
Robert W. Stack and Jerry W. Riffle
7. Gloeosporium and Gnomonia Leaf Diseases of Broadleaf Trees ... 16
Robert W. Stack and Kenneth E. Conway
8. Oak Leaf Blister 20
Kenneth E. Conway and John E. Watkins
9. Leaf Spots of Nanking Cherry and Chokecherry 22
Robert L. James and John E. Watkins
10. Western X-disease of Chokecherry 24
Glenn W. Peterson and David W. Johnson
11. Honeysuckle Leaf Blight 26
Jerry W. Riffle and John E. Watkins
12. Powdery Mildew of Lilac 30
Richard Dorset and Michael W. Ferguson
13. Cylindrosporium Leaf Spot of Buffaloberry and Skunkbush Sumac 32
Glenn W. Peterson and Jerry W. Riffle
14. Herbicides (Air Pollution) 33
Gary A. Boutz and Robert W. Stack
15. Chlorosis 36
Mark O. Harrell and Mark W. Andrews

Branch and Stem

16. Botryodiplodia Canker of Elms 38
Jerry W. Riffle and Joseph M. Krupinsky
17. Tubercularia Canker of Siberian Elm and Russian-olive 40
Joseph M. Krupinsky and James A. Walla
18. Botryodiplodia Disease of Russian-olive 42
Glenn W. Peterson and Harrison L. Morton
19. Phomopsis Canker of Russian-olive 44
Harrison L. Morton and Joseph M. Krupinsky
20. Botryodiplodia Canker of Sycamore 46
Robert Lewis, Jr. and Kenneth E. Conway
21. Cytospora Canker of Cottonwoods and Willows 48
James A. Walla and Kenneth E. Conway
22. Septoria Canker of Cottonwood and Hybrid Poplars 50
Jerry W. Riffle and David S. Wysong
23. Phomopsis Canker on Cottonwood 52
Theodore H. Filer, Jr. and Edward M. Sharon

24. Dothichiza Canker of *Populus* Species 54
David W. Johnson and Robert W. Stack
25. Cryptosphaeria Canker of Cottonwood and Aspen 56
Thomas E. Hinds and Jerry W. Riffle
26. Hypoxylon Canker of Aspen 58
Thomas E. Hinds and Mark O. Harrell
27. Thyronectria Canker of Honeylocusts 60
William R. Jacobi and Jerry W. Riffle
28. Stem Decays of Willow 62
James A. Walla and Robert W. Stack
29. Wetwood (Slime Flux) of Elm, Cottonwood, and Mulberry 64
David W. Johnson and Jerry W. Riffle
30. Crown gall of Cottonwood, Willow, and *Prunus* Species 66
Michael W. Ferguson and Richard Dorset
31. Hypoxylon Canker of Oaks 68
Kenneth E. Conway and Mark W. Andrews
32. Black Knot of Cherry and Plum 70
David S. Wysong and Mark O. Harrell
33. Plum Pockets 72
William R. Jacobi and John E. Watkins
34. Brown Rot of Stone Fruits 74
David S. Wysong and James A. Walla
35. Fire Blight of Pear, Apple, Cotoneaster, and Other Ornamental Shrubs and Trees 76
John E. Watkins and Mark W. Andrews
36. Witches'-Broom of Hackberry 78
Mark O. Harrell and Frederick J. Crowe
37. Perennial Woodrotting Fungi that Cause Stem Decays of Hardwoods 80
Jerry W. Riffle and James A. Walla
38. Phellinus Stem Decays of Hardwoods 83
Jerry W. Riffle and Kenneth E. Conway
39. Quince Rust 86
Kenneth E. Conway and Mark W. Andrews
40. Environmental Stress Effects 88
Donald F. Schoeneweiss

Vascular Wilts

41. Dutch Elm Disease 92
Robert W. Stack and John G. Laut
42. Dothiorella Wilt of Elm 94
Joseph M. Krupinsky and Robert L. James
43. Elm Yellows 96
Wayne A. Sinclair and David S. Wysong
44. Verticillium Wilt of Maple, Catalpa, and Elm 98
David S. Wysong and Mark O. Harrell
45. Oak Wilt 100
David S. Wysong and Edward M. Sharon
46. Mimosa Wilt 104
Mark W. Andrews

Root and Soil-Borne

47. Phymatotrichum Root Rot 106
Glenn W. Peterson and Charles Maier
48. Armillaria Root Rot 108
Lloyd R. Fuller and Robert L. James
49. Nematodes of Broadleaf Trees 110
Jerry W. Riffle and Joseph M. Krupinsky

CONIFER DISEASES
Foliage

50. Phomopsis Blight of Junipers 112
Glenn W. Peterson
51. Cercospora Blight of Junipers 114
Glenn W. Peterson and David S. Wysong
52. Kabatina Tip Blight of Junipers 116
Andrea Ostrofsky and Glenn W. Peterson
53. Brown Spot Needle Blight of Pines 118
Albert G. Kais and Glenn W. Peterson
54. Dothistroma Blight of Pines 120
Glenn W. Peterson and David S. Wysong
55. Naemacyclus (Cyclaneusma) Needle Cast of Pines 122
Glenn W. Peterson and James A. Walla
56. Rhizosphaera Needle Cast of Spruce 124
Darroll D. Skilling and James A. Walla

Branch and Stem

57. Western Gall Rust of Pines 126
Glenn W. Peterson and James A. Walla
58. Diplodia Blight of Pines 128
Glenn W. Peterson and David W. Johnson
59. Sirococcus Shoot Blight of Spruce 130
Kathryn Robbins and Edward M. Sharon
60. Cytospora Canker of Spruce 132
James A. Walla and Frederick J. Crowe
61. Antrodia Stem Decay of Eastern Redcedar 134
Edward M. Sharon and Jerry W. Riffle
62. Gymnosporangium Rusts on Junipers 136
James A. Walla and Jerry W. Riffle

Wilts

63. Pine Wilt Disease 138
Jerry W. Riffle and Frederick J. Crowe

Root and Soil-Borne

64. Root Lesion Nematodes in Junipers and Pines 140
Glenn W. Peterson and Jerry W. Riffle
Glossary 142
Index to Host Plants with Scientific Equivalents 145
Index to Plant Diseases and Pathogens 147
Index to Insect Vectors 149

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Introduction

cope

The purpose of this Handbook is to assist users in iagnosing tree diseases and reducing their impact. Inluded are the most damaging diseases, along with some hich, though of minor importance, are the subject of equent inquiry.

The diseases included are those encountered primari on trees in windbreak, Christmas tree, recreational, oadside, and landscape plantings in the Great Plains. iseases of fruit and nut trees are included when they re encountered on such trees that are used in the above ypes of plantings. Information on nutrient deficiencies s not included, except in the article on chlorosis. There s no extensive coverage of damage by airborne ollutants except that caused by herbicides.

The articles are organized under hardwood diseases nd conifer diseases; under each of these categories they re classified as to part of plant affected—foliage, branch nd stem, vascular wilt, and root and soilborne.

Most of the diseases are treated separately in the ollowing standard format: Hosts and Distribution, ymptoms and Signs, Disease Cycle, Damage, Control, nd Selected References. The emphasis is on disease ituations in the Great Plains. Accordingly, no special ffort has been made to include the total distribution of athogens, or to list all of their hosts. Similarly, Sympoms and Signs, and Diseases Cycles are described rimarily as observed in the Great Plains.

iagnosis

In making a diagnosis, the reader is referred first to he host index to see which diseases are listed for the ree host in question. Then the reader should check the vrite-up on the diseases on that host and also the hotographs to see if they conform with the diseases nder consideration. A glossary of technical terms is inluded for a more complete understanding of the articles. nglish units of measure are used for the most part; netric units are used primarily in descriptions of athogens.

ontrol

Information on control (reducing damage) is provided. Vhere chemicals are suggested or recommended, the eader should determine if the material is currently egistered for the intended use. Most of the articles listed n the Selected References were chosen because they will e useful in understanding the recommendations for educing damage. Information on the disease cycle of ome diseases is limited, thus the recommendations for heir control are quite general.

Damage due to pathogens can often be reduced by increasing the vigor of trees. Thus, the Control section of several of the articles in this Handbook include recommendations for increasing vigor. Vigor of trees in the Great Plains usually can be increased by supplemental watering. Application of fertilizers sometimes can result in increased tree vigor; however, the wholesale application of fertilizers for increasing tree vigor is not recommended. Use of fertilizers should be based on evidence that tree species of the age in question will respond to fertilizers on the sites involved.

History

There has been a demand for trees in the Great Plains since the early settlers wanted orchards, woodlots, windbreaks, and hedges. Long before the federal Timber Culture Act of 1873, individuals, companies, associations, and local governments had promoted tree planting in the Great Plains. Establishment of dry-land Agricultural Experiment Stations at Mandan, North Dakota; Woodward, Oklahoma; and Cheyenne, Wyoming resulted in increased planting of trees by farmers and ranchers, who cooperated with these stations in tests of tree species, cultural methods, spacing of trees, and the number of rows needed (Droze 1977).

The above work aided the U.S. Department of Agriculture's tree distribution program authorized by the Clarke-McNary Act, which was begun in 1924. This program, under the direction of the Extension Service of the USDA, encouraged tree planting in the Great Plains.

The biggest impetus to tree planting on the Great Plains came, however, when President Franklin D. Roosevelt, by executive order in July 1934, authorized the Shelterbelt Project. This Project, later called the "Prairie States Forestry Project", was operative between 1935 and 1942. It resulted in 223 million trees being planted in 18,600 miles of field windbreaks. Tree planting for protection purposes continued after 1942 under the direction of the USDA Soil Conservation Service.

Tree planting since 1942 has not been as extensive as during the Prairie States Forestry Project, but has been rather steady. The Soil Bank program of the 1960's resulted in an increase in Plains tree planting when considerable land was taken out of crop production and planted to trees.

The increased cost of energy has resulted in an increase in tree planting, not only on farms and ranches but in communities as well. Recently there has been an increase in use of trees in several Plains states for "living snow fence" established along roads.

A number of pest problems were noted in the early plantings in the Great Plains, but there was very little systematic study of tree diseases and insects with the exeption of research on diseases of seedlings (Dix, Pasek, and Peterson 1983).

Research on diseases of tree seedlings in the Great Plains was initiated some 70 years ago by Carl Hartley and colleagues of the U.S. Department of Agriculture. Their research resulted in a good understanding of damping-off disease of pines and other conifers (Hartley 1921) and provided some information on other diseases of conifer seedlings (Hartley, Merrill, and Rhoades 1918).

There was little additional tree disease research in the Great Plains until the period of the Prairie States Forestry Project (1935–1942). With the expansion of existing nurseries and the establishment of many new nurseries to provide trees for that project, a number of disease problems were encountered, particularly on hardwood seedlings. Thus, during this period, Ernest Wright and colleagues of the U.S. Department of Agriculture concentrated their research on disease problems of hardwood seedlings (Wright 1944, 1945), with some work being done on plantation diseases such as Phymatotrichum root rot (Wright and Wells 1948) and Cytospora canker of cottonwood (Wright 1957).

When the Prairie States Forestry Project was terminated in 1942, tree disease research in the Great Plains by the U.S. Department of Agriculture was discontinued. It was not resumed until 1958, when a plant pathologist position was established in the Lincoln Unit of the Rocky Mountain Forest and Range Experiment Station.

Prior to 1958 there had been occasional tree disease studies by Land Grant institutions in the Great Plains. Agricultural extension personnel in the Great Plains accumulated some information on tree diseases, but prior to 1960, they had little time to devote to tree problems. Also in the earlier periods, pest management specialists assigned to USDA Forest Service Regional Offices did not devote much time to tree disease problems in the Great Plains, other than those associated with federal nurseries and National Monuments.

Tree diseases in the Great Plains have received considerable attention since the early 1960's. Land grant institutions in North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma increased their research efforts; more extension plant pathologists were hired; USDA-FS pest management specialists increased their activities in the Plains, and pest management specialists were assigned to several State Forester's offices. Since 1958 there has been a continuous research effort on tree diseases by the Lincoln Unit; nursery diseases receive first attention, then later pine and juniper diseases i plantings were emphasized. With the addition of anothe pathologist to the Lincoln Unit in 1972, research was expanded to include additional research on hardwoo diseases and on mycorrhizae.

The increased effort on tree diseases prompted th Forestry Committee of the Great Plains Agricultura Council to establish a Pest Management Task Force t increase communication among workers and to coordinate activities in research, pest management, and extension. This task force sponsored the development o this Handbook.

References

Dix, Mary Ellen; Pasek, Judith E.; Peterson, Glenn W Forest insect and disease publications of the Grea Plains. Lincoln, NE: U.S.Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station; 1983. 42 p.

Droze, Wilmon H. Trees, prairies, and people. Denton TX: Texas Woman's University Press; 1977. 313 p.

Hartley, Carl. Damping-off in forest nurseries. Agric Bull. 934. Washington, DC: U.S. Department of Agriculture; 1921. 99 p.

Hartley, Carl; Merrill, T. C.; Rhoads, Arthur S. Seedlin diseases of conifers. Journal of Agricultural Research 15: 521–558; 1918.

Peterson, Glenn W. Pine and juniper diseases in th Great Plains. Gen. Tech. Rep. RM–86. Fort Collins, CO U.S. Department of Agriculture, Forest Service, Rock Mountain Forest and Range Experiment Station; 1981 47 p.

Wright, Ernest. Damping-off in broadleaf nurseries of th Great Plains Region. Journal of Agricultural Research 69: 77–94; 1944.

Wright, Ernest. Relation of macrofungi and microorganisms of soils to damping-off of broadleaf seedlings. Journal of Agricultural Research. 70: 133–141 1945.

Wright, Ernest; Wells, H. R. Tests on the adaptability trees and shrubs to shelterbelt planting on certai Phymatotrichum root rot infested soils of Oklahom and Texas. Journal of Forestry. 46: 256–262; 1948.

Wright, Ernest. Cytospora cankers of cottonwood. Plan Disease Reporter. 41: 892–893; 1957.

Use and Safe Handling of Pesticides

Some States have restrictions on the use of certain esticides. Check your State and local regulations. Also, ecause registrations of pesticides are under constant view by the U.S. Environmental Protection Agency, onsult your county agricultural agent or State extension ecialist to be sure the intended use is still registered.

The following rules should be followed when handling esticides. These rules should be read by all persons inolved in pesticide use. Copies of these rules should be osted in several places, particularly in the areas of esticide storage.

Pesticides are poisonous and always should be used ith caution. If used properly, they will not cause inury. The dangers associated with mishandling and isapplication of pesticides, however, include possible njury to the operator and handler, and damage to the eedling crop, to the equipment, and to the environment. ead the Health and Safety codes of your organization ertaining to use of toxic chemicals prior to use of esticides.

1. Read the label.—Handlers should read, understand, nd follow all instructions on the label. Notice warnings nd cautions before opening the container. Repeat the rocedure every time, no matter how familiar you think ou are with the directions. Apply the material only in he amounts and at the times specified.

2. Avoid contact.—Avoid inhaling sprays and dusts. void contact with skin and eyes. When directed by the label, wear the proper protective clothing and a mask. Do not eat or chew while spraying or dusting. Wash thoroughly before eating.

3. Apply safely.—Use only the specified dosages and mix as directed. Do not use your mouth to siphon liquids from containers or blow out clogged lines or nozzles. Use clean, well-functioning equipment to apply the pesticides. Do not spray with leaking hoses or connections. Do not work or allow others to work in the drift of the spray or dust.

4. Wash immediately.—Stop and wash off any pesticide spilled on the body. Remove contaminated clothing. Wash and change to clean clothing after spraying and dusting. Also, wash clothing each day before re-use.

5. Dispose of containers properly.—Always dispose of empty containers so that they pose no hazard to humans, animals, or plants (either terrestrial or aquatic). When in doubt on proper disposal procedures, contact the nearest agricultural authority.

6. Store safely.—Keep pesticides stored together outside the home or office away from food and usual working areas. Keep them under lock and key. Label and sign the area well and do not store other chemicals among the pesticides. Always keep the pesticides in the original containers, and keep them tightly closed.

7. Report illness.—If symptoms of illness occur during or shortly after dusting or spraying, call a physician or get the patient to a hospital immediately.

1. Melampsora Leaf Rust of Cottonwood and Willow

Glenn W. Peterson and Robert W. Stack

Cottonwoods and willows in the Great Plains are subject to loss in vigor due to leaf rust caused by *Melampsora* spp.

Hosts and Distribution

The common leaf rust of cottonwood in the Great Plains is caused by the fungus *Melampsora medusae*. In addition to cottonwood, several *Populus* hybrids and species including aspen are susceptible to this fungus. The fungus is present in the Great Plains from North Dakota to Texas. Other species of *Melampsora* infect willows.

Symptoms and Signs

The most obvious indicators of this disease are pustules (uredia) on the surfaces of leaves. These uredia are conspicuous because of the powdery masses of bright orange-yellow urediospores which they contain (figs. 1–1, 1–2). Highly susceptible trees may exhibit premature leaf drop, particularly in the lower crown, late in summer. Later, telia form on the fallen leaves. These appear as orange to brown waxy crusts.

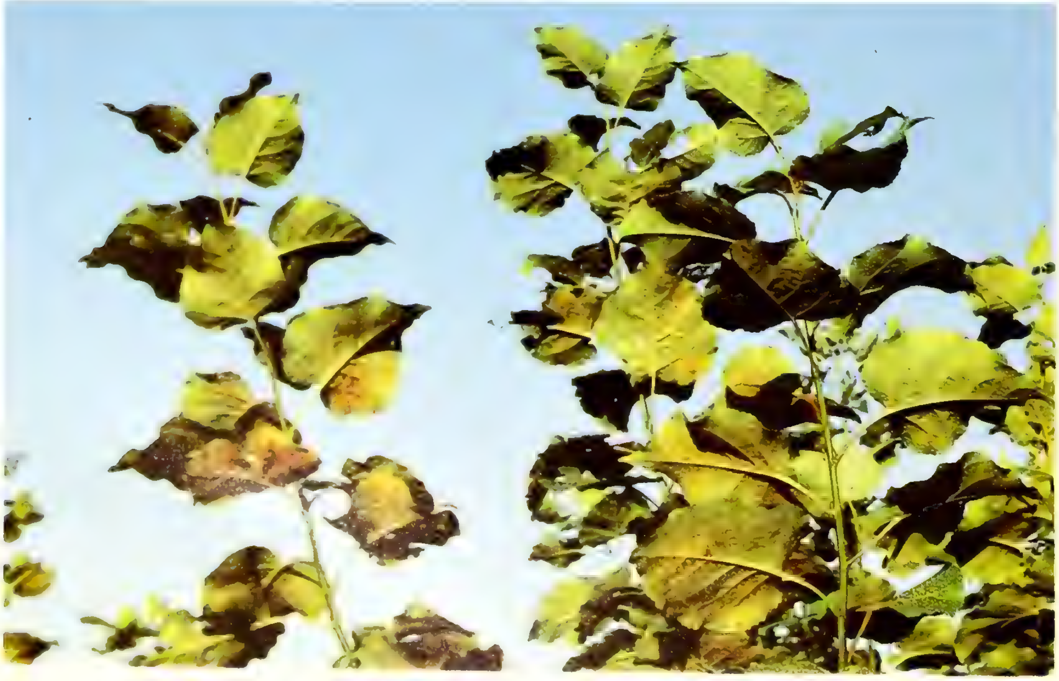
Disease Cycle

M. medusae requires two hosts to complete its life cycle. Larch and a few other coniferous hosts are infected by basidiospores, which are produced in spring on overwintered fallen cottonwood leaves. Infected larch produce aeciospores, which infect cottonwood in early summer. The infected cottonwood produces urediospores, which can re-infect cottonwood.

Telia are produced on cottonwood leaves in the fall. The telia overwinter on fallen leaves; in the spring the teliospores germinate and produce basidia and basidiospores. The cycle is completed with infection of larch or other coniferous hosts by basidiospores.

There is evidence that, in the Great Plains, this fungus is spread primarily from north to south by urediospores. Initial infection of cottonwood in the south is later than in the north; this suggests long-distance dispersal of urediospores from the north, presumably by wind

Figure 1-1. Branch with poplar leaves infected by *Melampsora medusae*.



ssibly, in some locations, uredia on cottonwood can
vive over winter and produce urediospores the fol-
ing growing season. In most areas of the Great Plains,
wever, it is unlikely that overwintered uredia are the
rce of primary infection of cottonwood.

mage

he primary effect of the rust on poplars is premature
f drop with accompanying loss of vigor. The early loss
leaves likely reduces carbohydrate reserves in tree
ts, which may be responsible for the decline of some
tonwoods in windbreaks.

ntrol

he impact of this disease can be reduced by use of
istant selections. The ease with which cottonwood
be produced vegetatively makes this a practical solu-
n. One of the resistant selections, 'Siouxland' cotton-
od, is highly susceptible to canker disease fungi, and
s, is no longer recommended for Great Plains plant-
s. Other resistant selections are available. The recog-
ion of pathogenic races of *Melampsora* on *Populus*
ecies in Australia and elsewhere suggests that any
sistant' clones may become susceptible to new races
the future.

he fungus could probably be controlled by fungicides.
is would not be practical in established plantings, but
y improve establishment in new windbreak plantings.
Mississippi, one application of cupric oxide controlled
rust on cottonwood in an experimental nursery.

Selected References

Chitzanidis, A.; Van Arsdel, E. P. Autumn introduction and winter survival of poplar rust on the Texas Coastal Plain. (Abstract) Phytopathology. 60: 582; 1970.

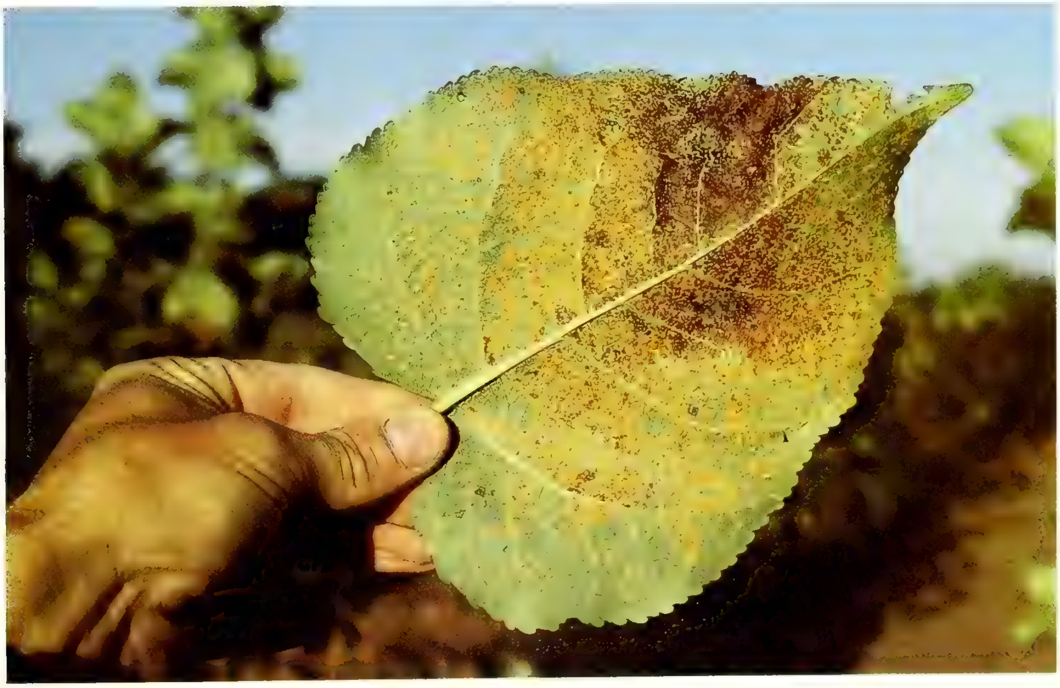
Filer, T. H., Jr. Melampsora rust on cottonwood. In: Forest Nursery Diseases in the United States. Agric. Handb. 470. Washington, DC: U.S. Department of Agriculture, Forest Service; 1975: 99–100.

Nagel, C. M. Leaf rust resistance within certain species and hybrids of *Populus*. (Abstract) Phytopathology. 39: 16; 1949.

Toole, E. Richard. *Melampsora medusae* causes cottonwood rust in lower Mississippi Valley. Phytopathology. 57: 1361–1362; 1967.

Ziller, Wolf G. Studies of western tree rusts. VI. The aecial host ranges of *Melampsora albertensis*, *M. medusae*, and *M. occidentalis*. Canadian Journal of Botany. 43: 217–230; 1965.

Figure 1-2. Poplar leaf infected by *M. medusae*.



2. Marssonina Leaf Spot of Cottonwood and Aspen

John E. Watkins and David S. Wysong

Marssonina leaf spot, a widespread and serious disease of native and hybrid poplars, can severely defoliate susceptible trees well before normal fall leaf drop. The disease is caused by fungi in the genus *Marssonina.*

Hosts and Distribution

Marssonina spp. are distributed widely on poplar in Europe and are native to North America. All species of poplar are hosts for these pathogens. *M. populi* damages quaking aspen in the Rocky Mountains and has been found on narrowleaf cottonwood, although the latter is not considered a highly susceptible host. Severe defoliation of eastern cottonwood by *M. brunnea* has been observed along the Mississippi River Valley from Mississippi to Iowa and as far west as Nebraska. Althoug *M. brunnea* defoliates most native poplars, it is mos damaging to susceptible clones grown under a short rotation intensive-management culture, and is considered significant threat to eastern cottonwood in centra United States.

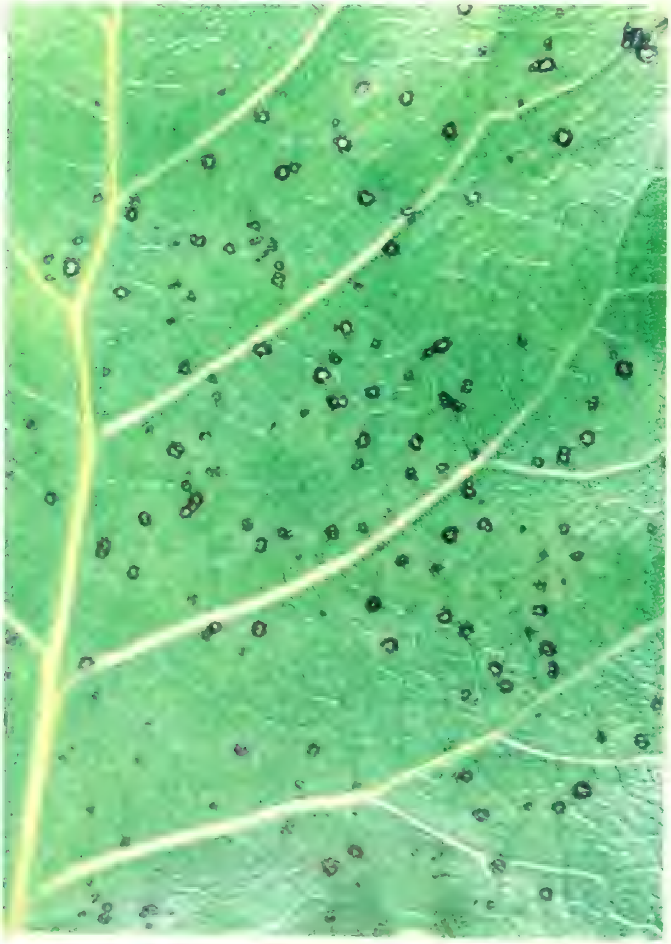


Figure 2-1. Marssonina leaf spots on a poplar leaf.

Symptoms and Signs

Dark brown flecks, often with yellow margins, appea on leaves within a few weeks after leaves emerge i spring. On eastern cottonwood, reddish-brown to purpl lesions develop on both leaf surfaces. These spots darke with age and gradually enlarge to 1–2 mm in diamete (fig. 2–1). Individual spots on severely infected leave may coalesce to form angular, necrotic blotches. The lea spots on quaking aspen vary in size, and are circular o lens-shaped. A yellow to golden margin often border each spot.

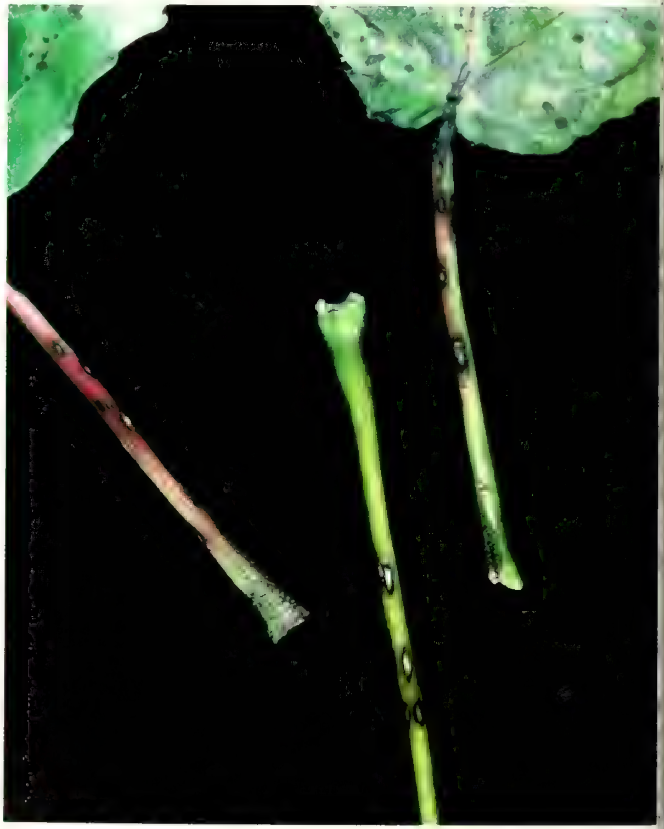


Figure 2-2. Elliptical lesions on petioles of poplar leaves caus by *Marssonina* sp.

Subcuticular lens-shaped fruiting bodies (acervuli), ntaining a white gelatinous mass of conidia, form ithin leaf lesions. As macroconidia are released, the idermis ruptures forming a small, ring-like blister g. 2–1).

Diseased leaves on affected trees appear smaller than rmal, turn yellow to bronze, and are shed premature- . The fungus moves progressively upward into the own. If viewed from a distance, the diseased leaves pear bronzed.

Elongate black lesions develop on veins, leaf petioles, d terminal sections of new shoot growth (fig. 2–2). haracteristic fruiting bodies also form on these struc- res and release masses of conidia.

Macroconidia of *Marssonina* are hyaline, unequally celled, ovate or pear-shaped, and are 11 to 16 μm by 5 to 7 μm (fig. 2–3). Microconidia are hyaline, 1–celled, liptical, and range from 3.3 to 5.5 μm by 1.2 to 1.8 μm. *arssonina* grows slowly in culture; it produces spores a yellow matrix, with portions of the colony turning ark as it matures (fig. 2–4).

isease Cycle

Primary infection is by conidia and ascospores pro- uced in overwintering fruiting bodies on fallen leaves r on infected shoots on the tree. In spring and early ummer, conidia are released and splashed by rain or arried by wind to newly emerged leaves and succulent oung shoots. Throughout summer and early fall, con- lia produced on leaf and shoot lesions are spread to her leaves and shoots, initiating secondary infections. pidemics coincide with the length and frequency of wet eather.

amage

In nurseries and plantations, the Marssonina leaf spot athogen causes only slight damage to cuttings and oung seedlings until sufficient inoculum develops on nfected shoots and on fallen leaf debris. On more stablished plantings and in native stands, repeated out- reaks result in branch and twig dieback and predispose ees to other pathogens or pests and to injury from low mperatures. Severe defoliation of eastern cottonwood y *M. brunnea* has been reported throughout much of e central and southern Mississippi River Valley.

ontrol

No fungicides are presently registered for control of arssonina leaf spot on poplar.

The most successful control is to plant poplars resist- nt or tolerant to Marssonina leaf spot. Current research, owever, indicates specialization in *Marssonina* spp. nfecting poplar. This must be taken into account in eveloping resistant cultivars.

The disease can be minimized on established suscep- ble poplars through sanitation. Removing dead and in- cted twigs from diseased trees and raking up and destroying fallen leaves during the growing season reduces primary and secondary infections. To restrict spread within the nursery and into home landscapes, nurserymen should take propagative cuttings only from disease-free shoots.

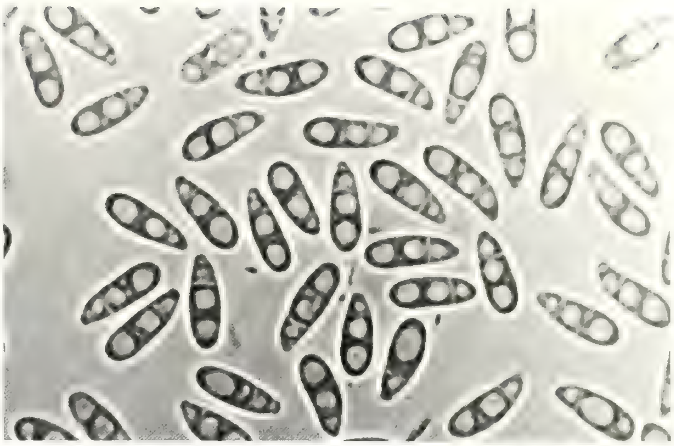
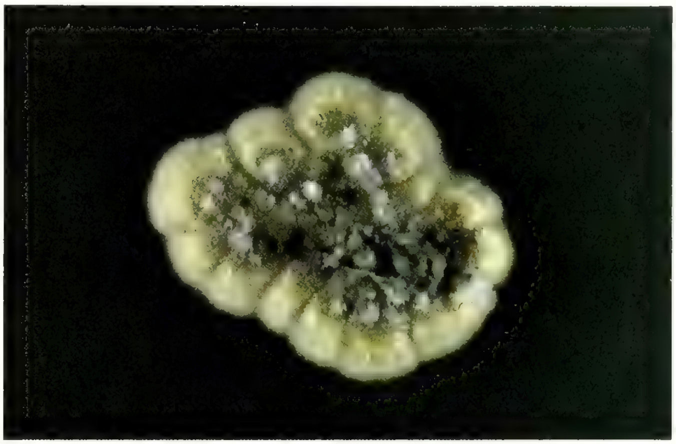


Figure 2-3. Macroconidia of *Marssonina* sp.

Figure 2-4. Colony of *Marssonina* sp. in pure culture.



Selected References

Davidson, R. M., Jr. Marssonina leaf and twig spot on willow. Washington State University Cooperative Extension Service Bulletin EM 4043; 1976.

Hepting, George H. Diseases of forest and shade trees in the United States. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture; 1971. 658 p.

Jokela, J. J.; Paxton, J. D.; Zegar, E. J. Marssonina leaf spot and rust on eastern cottonwood. Plant Disease Reporter. 60: 1020–1024; 1976.

Mielke, J. L. Aspen leaf blight in the Intermountain Region. Research Note 42. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1957. 5 p.

Palmer, M. A.; Ostry, M. E.; Schipper, Jr., A. L. How to identify and control Marssonina leaf spot of poplars. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1980.

3. Septoria Leaf Spots of Cottonwood, Caragana, and Maple

Joseph M. Krupinsky and David W. Johnson

Septoria leaf spots of cottonwood, maple, and caragana (Siberian peashrub) are caused by the fungi *Septoria musiva, S. aceris*, and *S. caraganae*, respectively. Because the life cycles of these fungi are similar and information on *S. aceris* and *S. caraganae* is limited, information on *S. musiva* on cottonwood will be presented as a general example of this type of disease.

Hosts and Distribution

S. musiva causes leaf spot and cankers on native and hybrid poplars commonly grown in windbreaks (fig. 3–1). The disease is widely distributed in Canada and the United States. *S. aceris* on maple is distributed throughout the United States, while *S. caraganae* has been reported on caragana in windbreaks in the Great Plains.

Symptoms and Signs

Symptoms reported for Septoria leaf spot on cottonwood vary according to time of infection, hosts, and texture and age of leaves. Four types of leaf spot symptoms have been described (figs. 3–2, 3–3):

1) Brown, mostly circular leaf spots that may have a brown or yellow margin, with pycnidia clustered within. These spots often are 1 cm in diameter.

2) Small flecks, commonly with very angular margins. Flecks may coalesce to form spots 2 to 10 mm across.

3) White or silvery spots, mostly 1 to 3 mm in diameter.

4) Irregularly shaped large spots that are light tan in the center, with a dark brown margin. Black pycnidia are commonly clustered in the center of spots (fig. 3–4). These spots may be several cm across; some look like targets because of rings or zones within the spot.

When leaves bearing pycnidia are under high humidity, conidia are discharged from the top of the pycnidia in pink or white curled spore horns. Because fungi other than *Septoria* can cause similar leaf spots, the type and size of the conidia must be examined for positive fungal identification. Conidia of *S. musiva* are hyaline, cylindric, straight or slightly curved, usually 2–4 septate, and 17–56 by 3–4 µm (fig. 3–5). *Septoria* leaf spots on maple species usually are small and reddish-tan to brown. The same fungus can also infect immature fruits of maple and cause browning. The conidia of *S. aceris* are cylindric, straight or slightly curved, usually 3 septate, and 20–43 by 2–3 µm. Conidia of *S. caraganae* are hyaline, usually 1–3 septate, and 30–50 by 2.5–3.5 µm.

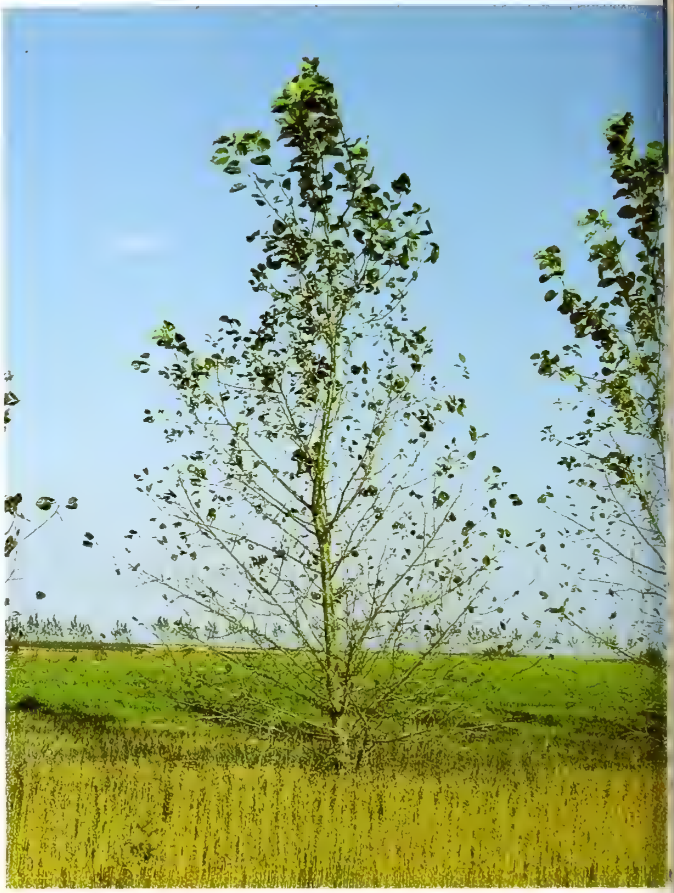


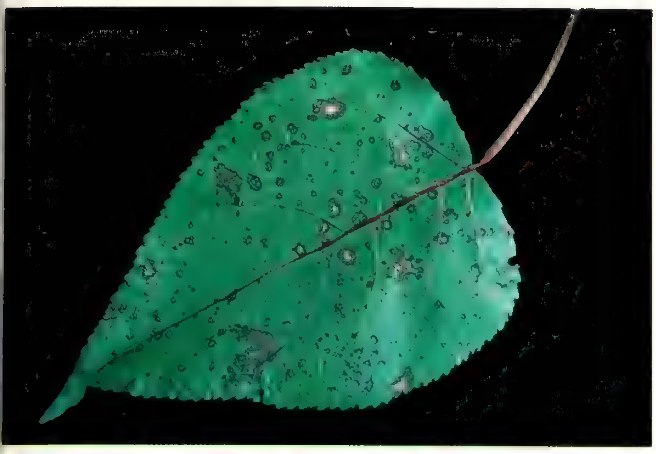
Figure 3-1. Defoliation of Northwest poplar by *Septoria musiva*

Disease Cycle

S. musiva overwinters in dead leaves and twigs infected the previous growing season. Initial infections in spring are from ascospores (sexually produced spores) released from fungal fruiting structures on fallen infected leaves. The perfect stage of *S. musiva* is *Mycosphaerella populorum*. Ascospores are 1 septate, hyaline, and 16–28 by 4.5–6 µm. Primary infections are mostly confined to leaves on lower branches. During summer rains, conidia produced on leaf spots may be washed from infected leaves and twigs, causing secondary infections. With favorable conditions of moisture and high humidity, numerous infections result in yellowing of leaves and premature defoliation. In new nurseries or plantings, infections can develop from spores lodged on cuttings from infected stool beds, from windborne spores from nearby infected cottonwood trees, and from spores produced on young cankers on the planting stock.

Damage

Numerous infections can result in premature defolia-



gure 3-2. Circular leaf spots on leaf of Northwest poplar infected by *S. musiva*.

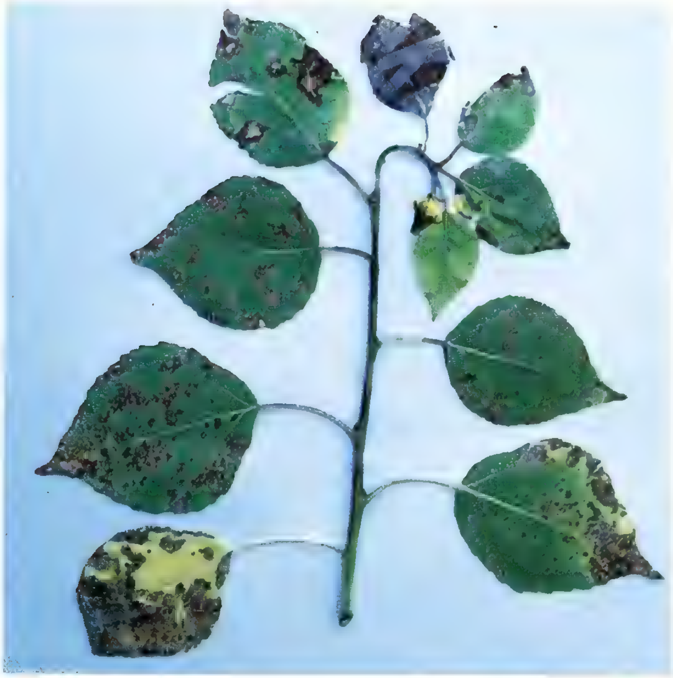


Figure 3-3. Range of leaf spot symptoms on Northwest poplar inoculated with *S. musiva*.

on of highly susceptible trees. Multiple cankers can rdle stems. Individual cankers are possible infection urts for other pathogens such as *Cytospora*, *Phomop*- s, and *Fusarium* that can girdle stems. When conditions e favorable, *S. caraganae* can become epidemic and use premature defoliation.

ontrol

These pathogens are best controlled by planting only sistant or tolerant clones. Spraying stool beds with a ngicide and spacing trees to provide good aeration and duce high humidity may reduce infection of leaves and ems. Sanitation is also important in stool beds. All in- cted overwintering leaves and stems should be re- oved to prevent new shoots from becoming infected ascospores. Sanitation in the field—burial or removal leaves and stems—can reduce primary infections in e spring.

elected References

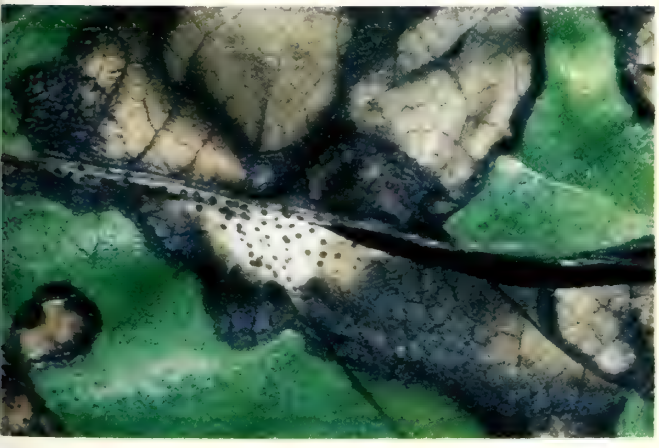
ler, T. H., Jr. Septoria leaf spot and canker on cottonwood. In: Forest Nursery Diseases in the United States. Agric. Handb. 470. Washington, DC: U.S. Department of Agriculture; 1975: 101–103.

Kennedy, Patrick C. Insects and diseases of Siberian pea shrub (Caragana) in North Dakota, and their control. Research Note RM–104. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1968. 4 p.

Palmer, Marguerita A.; Schipper, Arthur L. Jr.; Ostry, Michael E. How to identify and control Septoria leaf spot and canker of poplar. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1980. 6 p.

Thompson, G. E. Leaf-spot diseases of poplars caused by *Septoria musiva* and *S. populicola*. Phytopathology. 31: 241–254; 1941.

Waterman, Alma M. Septoria canker of poplars in the United States. Circular 947. Washington, DC: U.S. Department of Agriculture; 1954. 24 p.



igure 3-4. Pycnidia of *S. musiva* within leaf spot lesions.

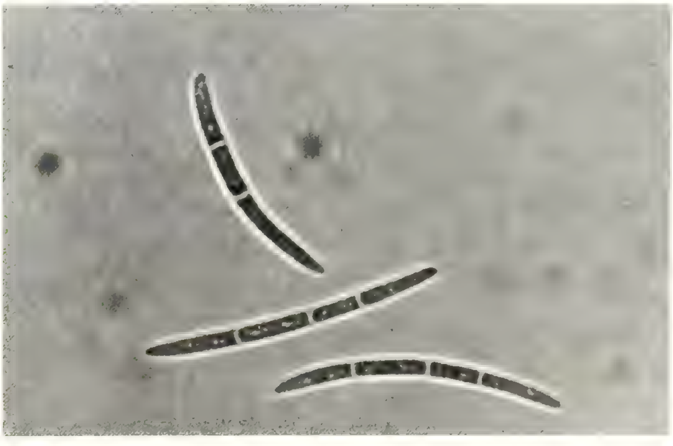


Figure 3-5. Conidia of *S. musiva*.

4. Phyllosticta Leaf Spots of Maple and Caragana

Robert L. James and David W. Johnson

Leaf spots are common diseases of maples and caragana (Siberian peashrub) throughout the Great Plains. Maples are important ornamentals, and caragana is commonly planted in windbreaks.

Hosts and Distribution

Phyllosticta minima commonly causes leaf spots on most native, as well as several introduced, maple species. The most commonly reported hosts include silver, sugar, red, and mountain maples. The disease occurs throughout the range of maple, including most portions of the Great Plains.

Phyllosticta gallarum causes similar leaf spots on caragana throughout the Great Plains and as far west as Alaska and east to Wisconsin.

Symptoms and Signs

Phyllosticta spp. produce either single distinct spots on leaves, or irregular necrotic patterns indicating coalescence of several spots (fig. 4–1). Host tissue, age, and several environmental factors are thought to influence differences in spotting characteristics. Individual spots are usually 3–4 mm in width and are irregularly circular. At first the spots appear entirely dark brown later they develop a pale, somewhat bleached center and a dark margin which is often reddish or purple-brown (fig. 4–2). Usually, large numbers of tiny black dots (pycnidia) are seen, often in circular patterns, within the center of spots (fig. 4–3). Premature leaf abscission may occur if there is sufficient infection.

Disease Cycle

Little is known of the disease cycle of *Phyllosticta* spp on maple and caragana. However, these pathogens probably act similarly to *Phyllosticta* species that have been studied more thoroughly on other hosts.

Initial infection of leaves in the spring is probably caused by windborne ascospores of perfect stages (mostly *Mycosphaerella* and *Guignardia*) arising from nearby previously infected, fallen leaves. The pathogen subsequently increases and spreads through infection by conidia, which are produced in black pycnidia within necrotic spots on leaves. Conidia are produced and released during periods of rain and high humidity, and are likely dispersed by rain splash. Initial spring infection occurs from late April to early May; subsequen secondary infections develop throughout the growing

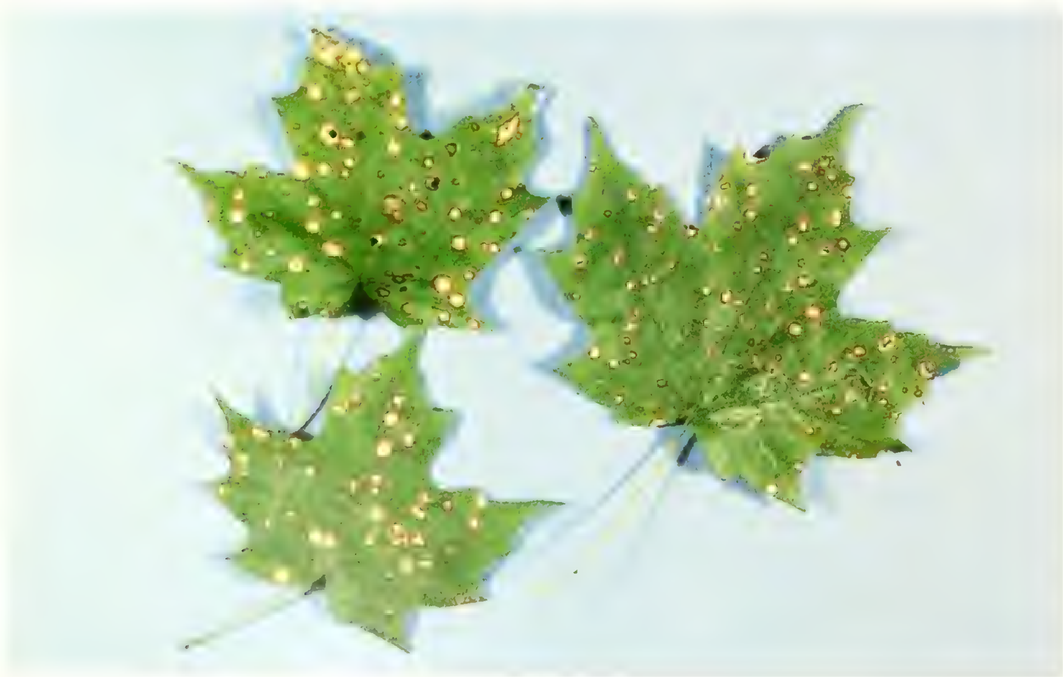


Figure 4-1. Phyllosticta leaf spots on sugar maple.

ason. These pathogens may cause premature defolia- n of heavily infected trees. Extensive defoliation by id-June has been reported on red maple severely in- cted with *P. minima*.

Phyllosticta species may infect seed on other hosts and use branch and stem cankers, which serve as sources primary inoculum in the spring. However, this type infection has not been demonstrated on maple or ragana.

amage

Phyllosticta leaf spots usually cause little damage. dividual trees may have extensive leaf infections and me premature defoliation may occur; however, overall mage to the host is usually minimal.

There have been a few reports of relatively severe foliation caused by these pathogens. However, the ported damage is usually associated with above normal infall in the spring, or is restricted to tree nurseries.

ontrol

Control of leaf spots is usually neither necessary nor onomically feasible. However, if control is deemed cessary, damage can usually be reduced by proper ap- ication of fungicide. Bordeaux mixture has been effec- ve against several leaf spot diseases, including those used by *Phyllosticta*. Other effective chemicals include nomyl and captan. Three applications of fungicide at proximately 3–4 week intervals in the spring and early mmer are generally sufficient to give adequate control.

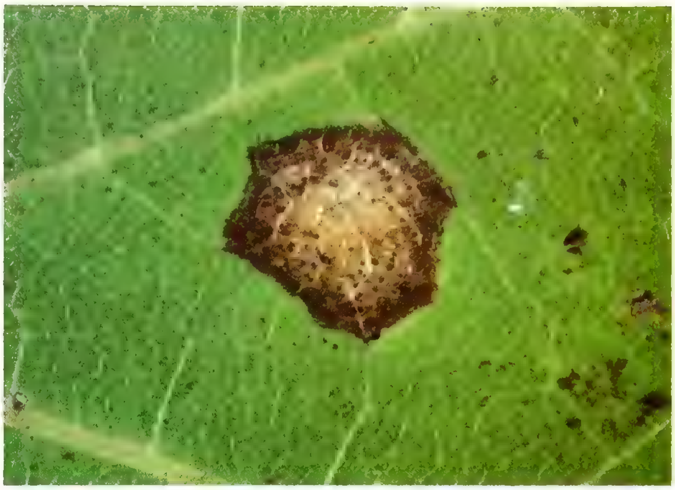


Figure 4-3. Pycnidia (black dots) of *Phyllosticta* sp. in necrotic leaf spot.

Selected References

Anderson, P. J. Index to American species of *Phyllosticta*. Mycologia. 11: 66–79; 1919.

Fergus, Charles L. An epiphytotic of Phyllosticta leaf spot of maple. Plant Disease Reporter. 38: 678–679; 1954.

Guba, E. F.Phyllosticta leaf spot, fruit blotch and canker of the apple; its etiology and control. Phytopathology. 14: 234–237; 1924.

James, Robert L. Leafspot of silver maple seedlings at Bessey Nursery, Nebraska. Biological Evaluation, R2-79-3. Denver, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region; 1979. 6 p.

Kohl, Edwin J. Investigations on apple blotch. Phytopathology. 22: 349–369; 1932.

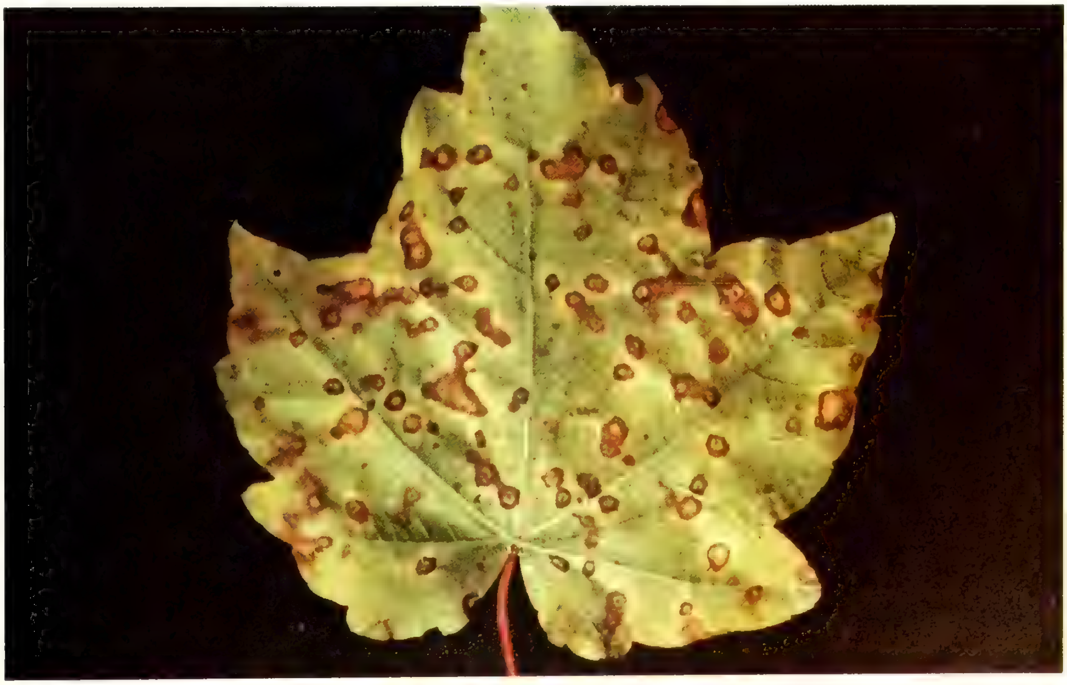


Figure 4-2. Phyllosticta leaf spots on red maple.

5. Tar Spot of Maple

Edward M. Sharon and Jerry W. Riffle

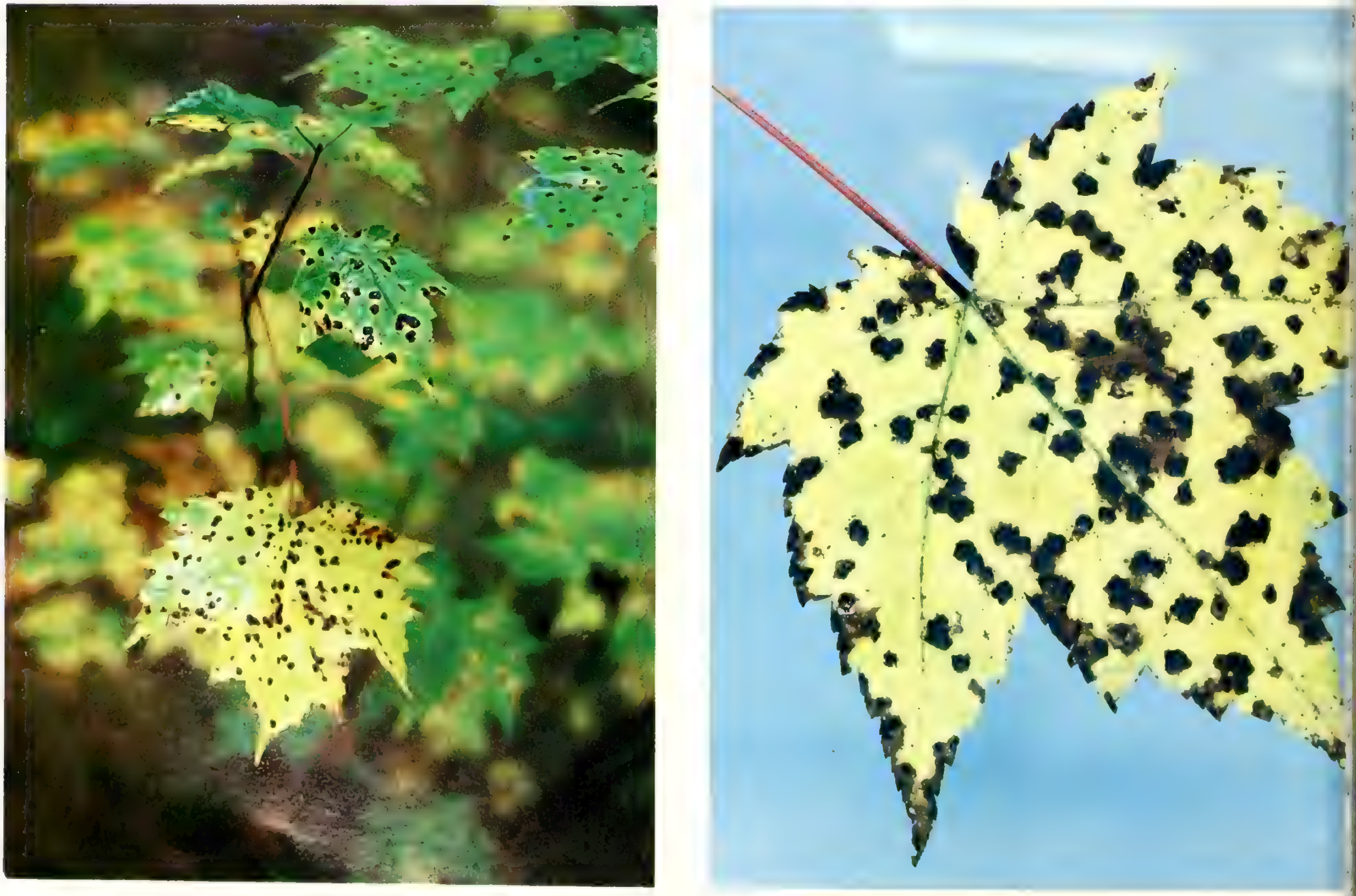
Tar spot on maples is caused by the fungus *Rhytisma acerinum* and related species. Other species of *Rhytisma* cause tar spot of other hosts.

Hosts and Distribution

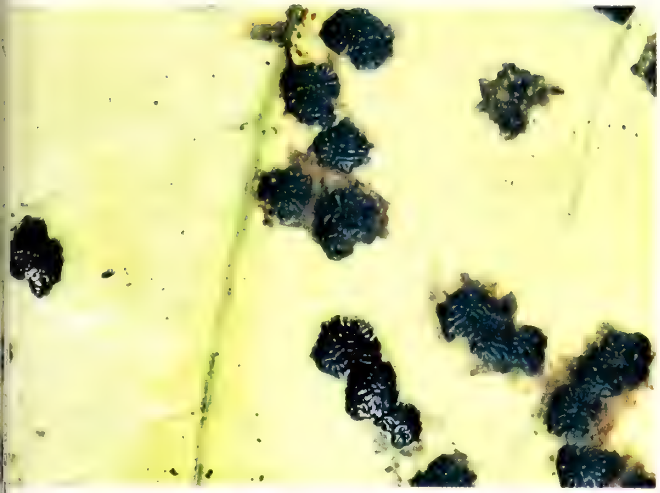
Tar spot is a foliage disease common to red and silver maples; it has also been reported on bigleaf, Norway, sugar, and sycamore maples. The disease occurs on maples throughout the eastern and Great Lakes states, in Oregon and Washington, and in Manitoba. Tar spot occurs on maple in Nebraska, but its distribution in other states of the Great Plains is uncertain.

Symptoms and Signs

One or more small greenish-yellow spots on the upper leaf surface indicates early infection. These spots appear from mid to late July. By late summer, conspicuous black tar-like structures, up to one-half inch in diameter, form within the chlorotic areas (fig. 5–1). The lower leaf surface opposite the tar-like structures is cupped and less black. By mid-fall the tar spots appear ridged and are sometimes referred to as "wrinkled scab" (figs. 5–2, 5–3). The tar spots are stromata, which contain two types of fruiting bodies, spermogonia and apothecia.



Figures 5-1 and 5-2. Tarspots on maple leaves infected with ***Rhytisma acerinum.***



gure 5-3. Close-up of tar-like structures (stromata) of *R. acerinum* on maple leaf.

isease Cycle

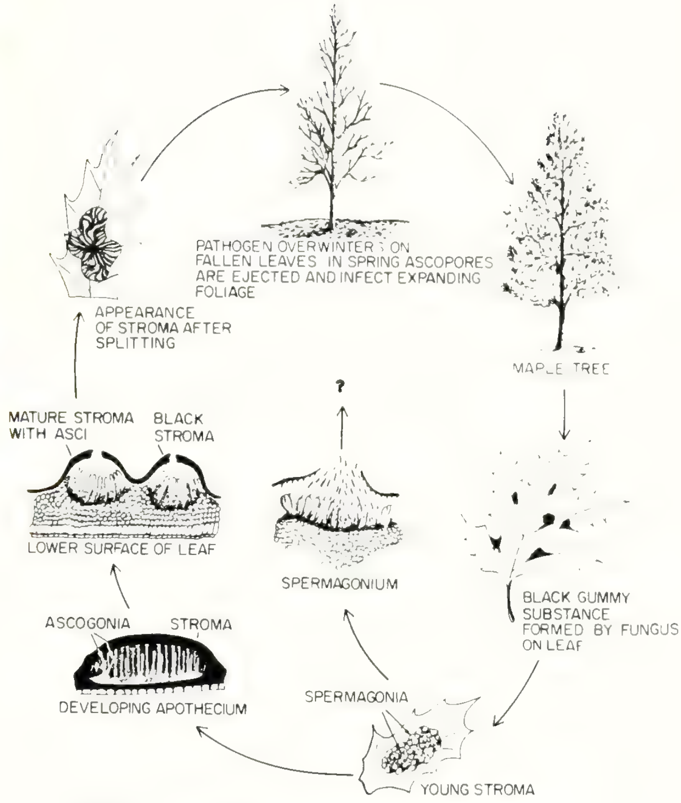
Ascospores of *R. acerinum* develop in the stromata ter leaves are cast, and these spores mature in the ring (fig. 5–4). In the spring ascospores are forcibly ected from apothecia on fallen leaves. The spores are ected a limited distance and are carried upward on air rrents, where they make contact with expanding liage of susceptible trees. The fungus enters leaves rough stomates, and produces a black gummy bstance within the tissues. This substance binds host d fungus together to form a stroma beneath the upper idermis of the leaf. At this time the infected spot apears as a definite blackened area fringed with a llowish-green border. First spermogonia, and later othecia, develop within this tissue before the leaves op.

Numerous spermogonia develop in a group at the nter of the stroma. They look like small pimples with minute hole in the center, and represent the imperfect age *Melasmia acerina*. Simple or branched coniophores are formed within the spermogonia. The ngle-celled spermatia are hyaline or subhyaline, rodaped, 6 by 1 μm and are not infectious.

The stromata continue to expand and develop radiing wrinkles in which apothecia form. During the inter, asci develop slowly; by early spring their development is completed. Each ascus contains eight needle-like scospores, approximately 130 by 10 μm. Ascospores are rcibly ejected when the stroma splits along the diating wrinkles. Air currents carry the spores to new liage, and new infections develop.

amage

Tar spot seldom severely impacts the health of trees. is not known to kill trees. Open-grown trees are seldom fected. In sheltered situations, such as in the forest, trees can be heavily infected and defoliate prematurely. Successive years of defoliation may predispose trees to other pests. Premature defoliation of infected leaves gives an appearance of crown thinning.


PATHOGEN OVERWINTERS ON FALLEN LEAVES. IN SPRING ASCOPORES ARE EJECTED AND INFECT EXPANDING FOLIAGE
APPEARANCE OF STROMA AFTER SPLITTING
MAPLE TREE
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MATURE STROMA WITH ASCI
BLACK STROMA
LOWER SURFACE OF LEAF
SPERMAGONIUM
BLACK GUMMY SUBSTANCE FORMED BY FUNGUS ON LEAF
ASCOGONIA
STROMA
DEVELOPING APOTHECIUM
SPERMAGONIA
YOUNG STROMA

Figure 5-4. Disease cycle of *R. acerinum* on maple.

Control

The disease can be controlled in shade trees by raking and burning fallen leaves to destroy overwintering inoculum. If spraying is warranted, Bordeaux mixture is considered satisfactory. Apply fungicide at 2–3 week intervals during leaf emergence.

Selected References

Alexopoulos, Constantine John. Introductory mycology. 2nd Edition, New York: Wiley; 1962. 613 p.

Boyce, John Shaw. Forest pathology. New York: McGraw-Hill; 1961. 572 p.

Carter, J. Cedric. Diseases of Midwest trees. Urbana: University of Illinois Press; 1979. 168 p.

Marshall, Rush P.; Waterman, Alma M. Common diseases of important shade trees. Farmer's Bulletin 1987. Washington, DC: U.S. Department of Agriculture; 1948. 53 p.

May, Curtis. Diseases of shade and ornamental maples. Agric. Handb. 211. Washington, DC: U.S. Department of Agriculture; 1961. 22 p.

6. Mycosphaerella Leaf Spots of Ash

Robert W. Stack and Jerry W. Riffle

Two leaf spot diseases of ash are caused by species of *Mycosphaerella*. The disease most common in nurseries is caused by *Mycosphaerella effigurata*, and is known as 'Piggotia leaf disease', 'Mycosphaerella leaf spot', or 'Marssonina leaf blight'. The fungus is pleomorphic, consisting of a conidial stage (*Marssonina fraxini*), a spermogonial and carpogonial stage (*Phyllosticta fraxini, Piggotia fraxini*), and a perithecial stage (*M. effigurata*). The other disease, less common but widely distributed, is caused by *Mycosphaerella fraxinicola*, and is known as 'Phyllosticta leaf spot'. The spermogonial stage of this fungus is *Phyllosticta viridis*.

Hosts and Distribution

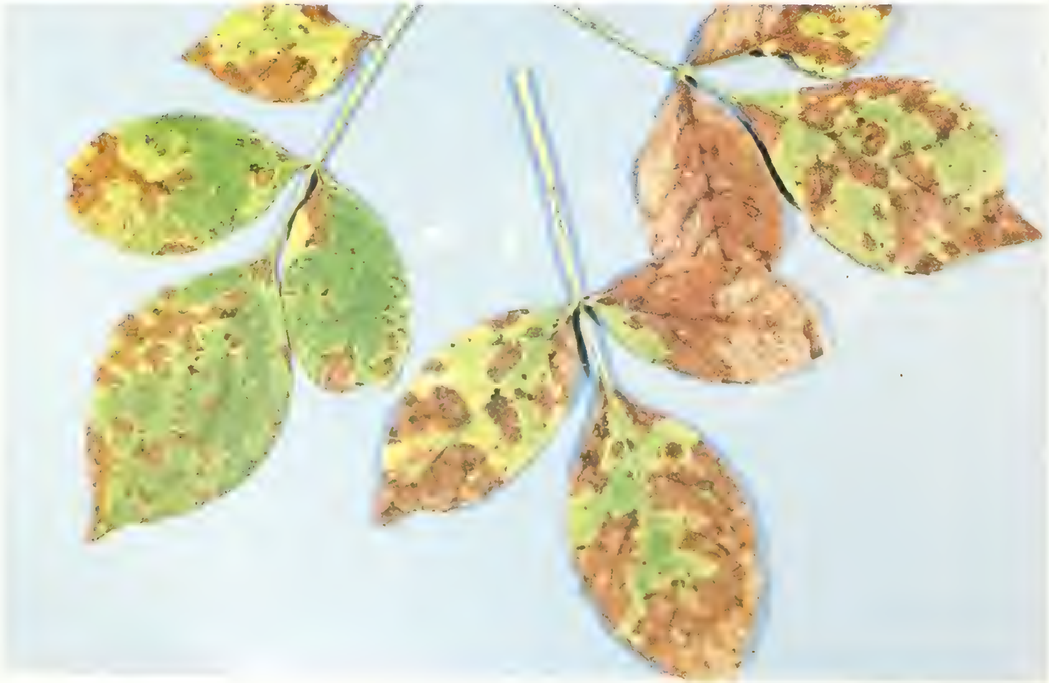
The foliage diseases caused by these two fungi are distributed throughout the Great Plains wherever ash is grown. All commonly grown species of ash (green, white, and black) are hosts of these fungi. No resistant speci or cultivars of ash are known. Uniformly high levels infection with little variation among individuals or see sources have been observed in nursery beds.

Symptoms and Signs

Although usual symptoms of the two leaf spot diseas are distinct, diagnosis is difficult because symptoms ma intergrade, both fungi may be present on the same lea and the causal agents are pleomorphic.

Phyllosticta leaf spot usually appears as rounded to i regular spots or blotches, typically 0.2–0.6 inch acros in mid to late summer (fig. 6–1). The spots initially a pale green, and turn light brown or tan by early Septe ber. In severe outbreaks the spots enlarge and coalesc blighting entire leaves. The entire crown of large tre may appear scorched during the outbreaks.

Figure 6-1. Leaf spot on green ash caused by *Mycosphaerella fraxinicola.*



Symptoms of Mycosphaerella leaf spot first appear in ne. Scattered yellow spots, approximately 1–3 mm in ze, develop on the upper leaf surface. If the spots are merous the entire leaf may appear yellow. Conidia are oduced in immersed acervuli on the lower leaf surface. veral weeks after the first symptoms appear, numerous nall dark stromata, which contain carpogonia and sper- ogonia, develop over the lower leaf surface. By fall the ack stromata give the lower leaf surface a rough sooty pearance (fig. 6–2). The upper leaf surface remains een.

isease Cycle

Both *M. effigurata* and *M. fraxinicola* develop rithecia in fallen leaves over winter. Ascospores of th species are 2–celled, and are similar in shape but t in size. *M. effigurata* ascospores are 4 by 15 µm, while ose of *M. fraxinicola* are 4–5 by 8–10 µm. In spring the cospores are dispersed by wind to infect new leaves. fection by ascospores of *M. effigurata* appears as inute yellow spots in June. Two-celled hyaline conidia rm in acervuli below spots, and the conidia may cause condary leaf infections. Phyllosticta leaf spot has only primary disease cycle; spores produced in the sper- ogonial stage are not infectious. Infections by cospores of *M. fraxinicola* do not become evident un- mid or late summer in contrast to *M. effigurata*.

Damage

M. effigurata is especially common in nurseries and on young trees where it may cause premature defoliation. In at least one Northern Great Plains nursery the early defoliation caused by this fungus is considered beneficial by the nursery manager as it causes leaf drop before early snowfall.

M. fraxinicola may cause severe premature defoliation on large established trees. If repeated for several seasons, such defoliation might affect growth increment.

Control

Defoliation by either of these fungi occurs too late in the season to cause renewed growth or winter hardiness problems. No specific controls are known for these diseases.

Selected References

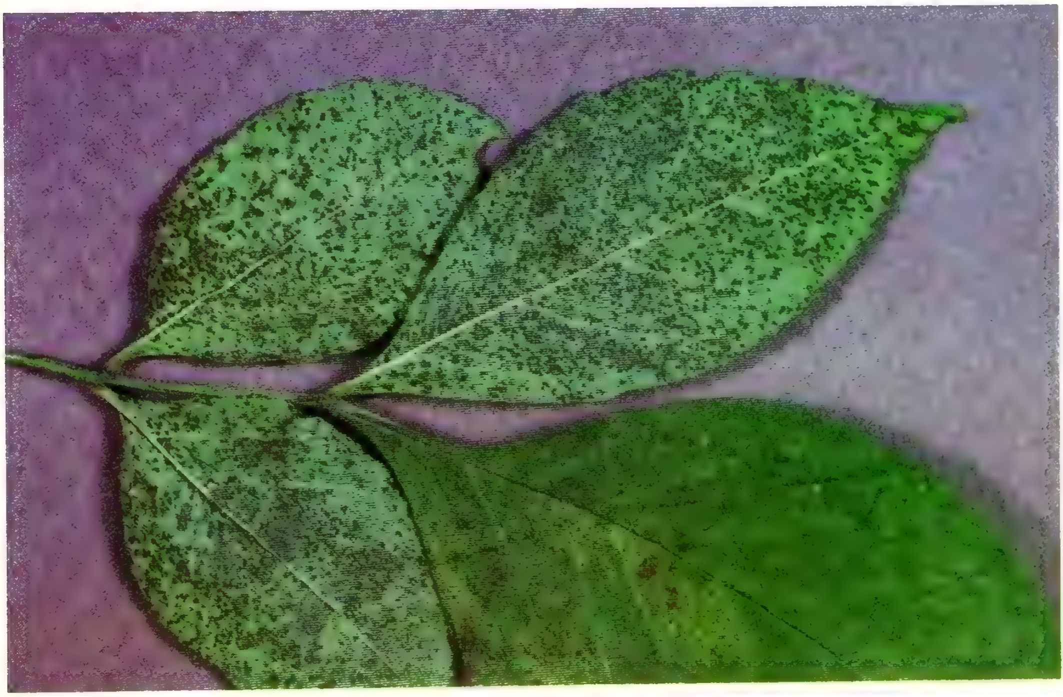
Conners, I. L. An annotated index of plant diseases in Canada. Agric. Publ. 1251. Ottawa: Canada Department of Agriculture; 1967. 381 p.

Hepting, George H. Diseases of forest and shade trees of the United States. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture; 1971. 658 p.

Wolf, Fredrick A. Leafspot of ash and *Phyllosticta viridis*. Mycologia. 31: 258–266; 1939.

Wolf, Fredrick A.; Davidson, Ross W. Life cycle of *Piggotia fraxini* causing leaf disease of ash. Mycologia. 33: 526–539; 1941.

Figure 6-2. Black stromata on lower leaf surface of green ash nursery seedlings caused by *M. effigurata*.



7. Gloeosporium and Gnomonia Leaf Diseases of Broadleaf Trees

Robert W. Stack and Kenneth E. Conway

Many trees are affected by diseases caused by fungi of the genus *Gnomonia* and its asexual stage *Gloeosporium*. Diseases caused by these fungi are commonly called 'anthracnose.' The site of infection, kinds of symptoms and signs, and severity of anthracnose disease varies from species to species and often from year to year. The only symptom commonly found on maples and elms may be leaf spot or leaf blight (figs. 7–1, 7–2). In other species, such as sycamore and white oaks, the entire range of anthracnose symptoms may occur, including bud, twig, and shoot blights, leaf spots, and stem cankers.

Hosts and Distribution

Gnomonia-caused diseases are widespread throughou the native and planted ranges of their respective hosts The pathogens and their hosts growing on the Grea Plains are summarized in table 7–1.

Each species of *Gnomonia*/*Gloeosporium* is specific fo a particular host genus, with little or no cross pathogenicity as far as is known. For each host, the symptom may differ based on the part of the tree attacked (tabl 7–1). The taxonomy of *Gnomonia*/*Gloeosporium* has bee revised, but the more familiar names for the anthracnos pathogens are presented.

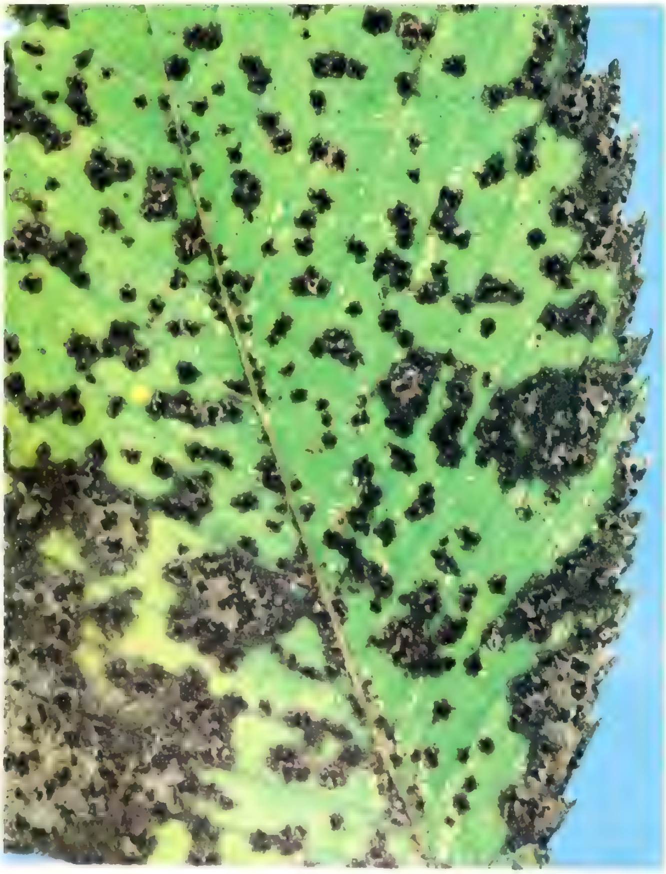


Figure 7-1. Black leaf spot of elm caused by *Gnomonia ulmea*.

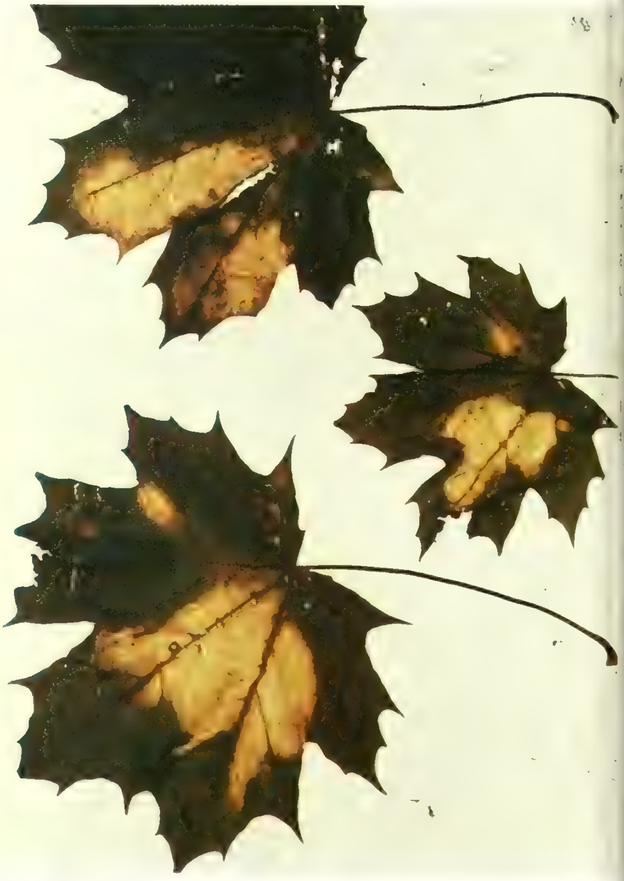
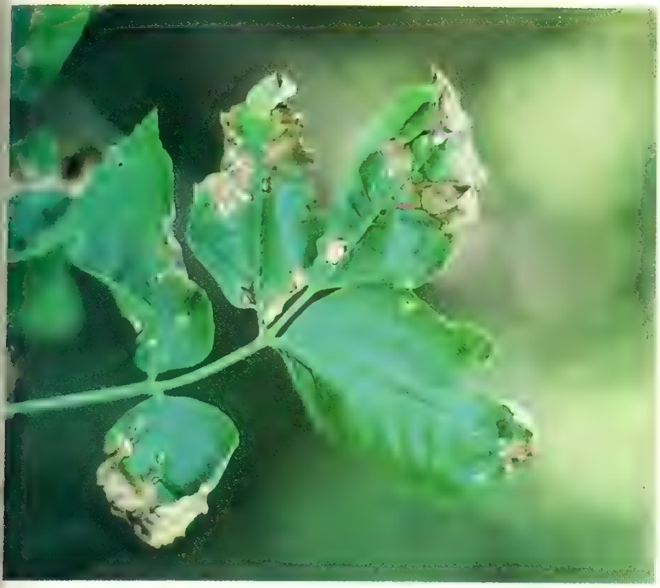


Figure 7-2. Symptoms of maple anthracnose caused b *Gloeosporium apocryptum*.



igure 7-3. Leaf distortion and necrosis of green ash caused by *Gloeosporium aridum*.

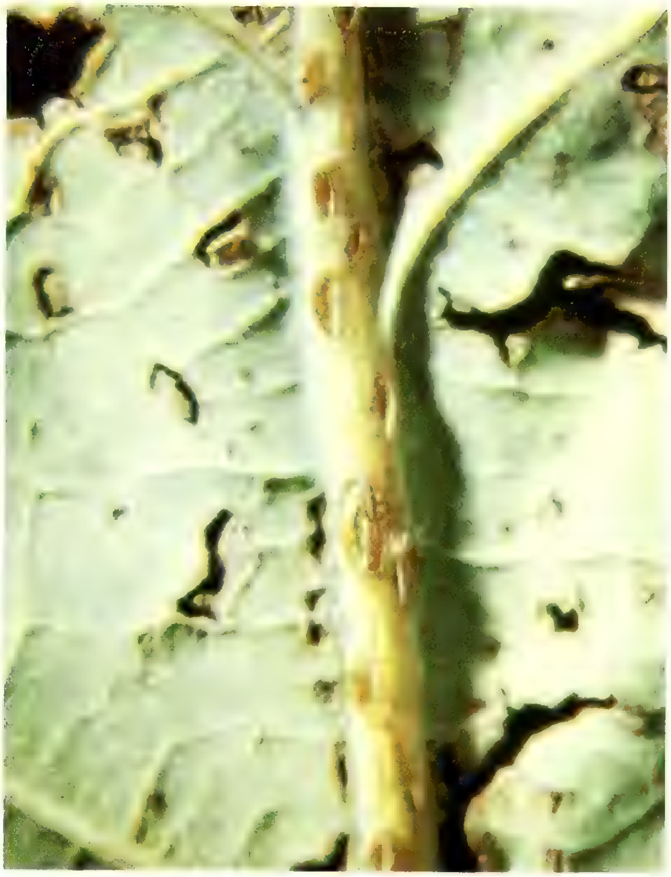


Figure 7-4. Acervuli of *Gnomonia quercina* on midvein of oak.

ymptoms and Signs

Leaf infections early in the season result in blotching, istortion, and large necrotic areas. These symptoms are ypical of ash, oak, and sycamore anthracnose (fig. 7–3 hrough fig. 7–6). Later leaf infections result in discrete mall to large spots, often surrounded by a dark ring or chlorotic halo. Such spots are the principal symptoms n basswood, elm, and maple (figs. 7–1, 7–2). Severe leaf pot infection may cause extensive defoliation, especially n ash and walnut.

On sycamore and oak, four phases of anthracnose can e distinguished—twig blight, bud blight, shoot blight, and leaf blight; leaf blight is already described above. In the twig blight phase, small, 1– or 2–year-old twigs are girdled and killed (fig. 7–5). Later, larger twigs and branches may be cankered and killed. In the bud blight phase, buds are penetrated by the fungus and killed before they expand. In the shoot blight phase, new young shoots and expanding leaves are suddenly killed. In sycamore (and probably other hosts), severe shoot blight depends on temperature, with infection greatest when temperatures are 50° to 59° F. In walnut, optimal infection temperature is 70° F.

Table 7–1. *Gloeosporium* and *Gnomonia* anthracnose pathogens and host trees on the Great Plains.

Host	Pathogen	Parts of tree attacked
Ash, esp. green	*Gloeosporium aridum*	Leaves, twigs
Basswood	*Gnomonia tiliae*	Leaves, twigs
Elm	*Gnomonia ulmea*	Leaves
Maple	*Gloeosporium apocryptum*	Leaves
Oak, esp. white	*Gnomonia quercina*	Leaves, twigs, shoots, buds
Sycamore and London plane-tree	*Gnomonia platani*	Leaves, twigs, shoots, buds
Walnut	*Gnomonia leptostyla*	Leaves, twigs, nuts

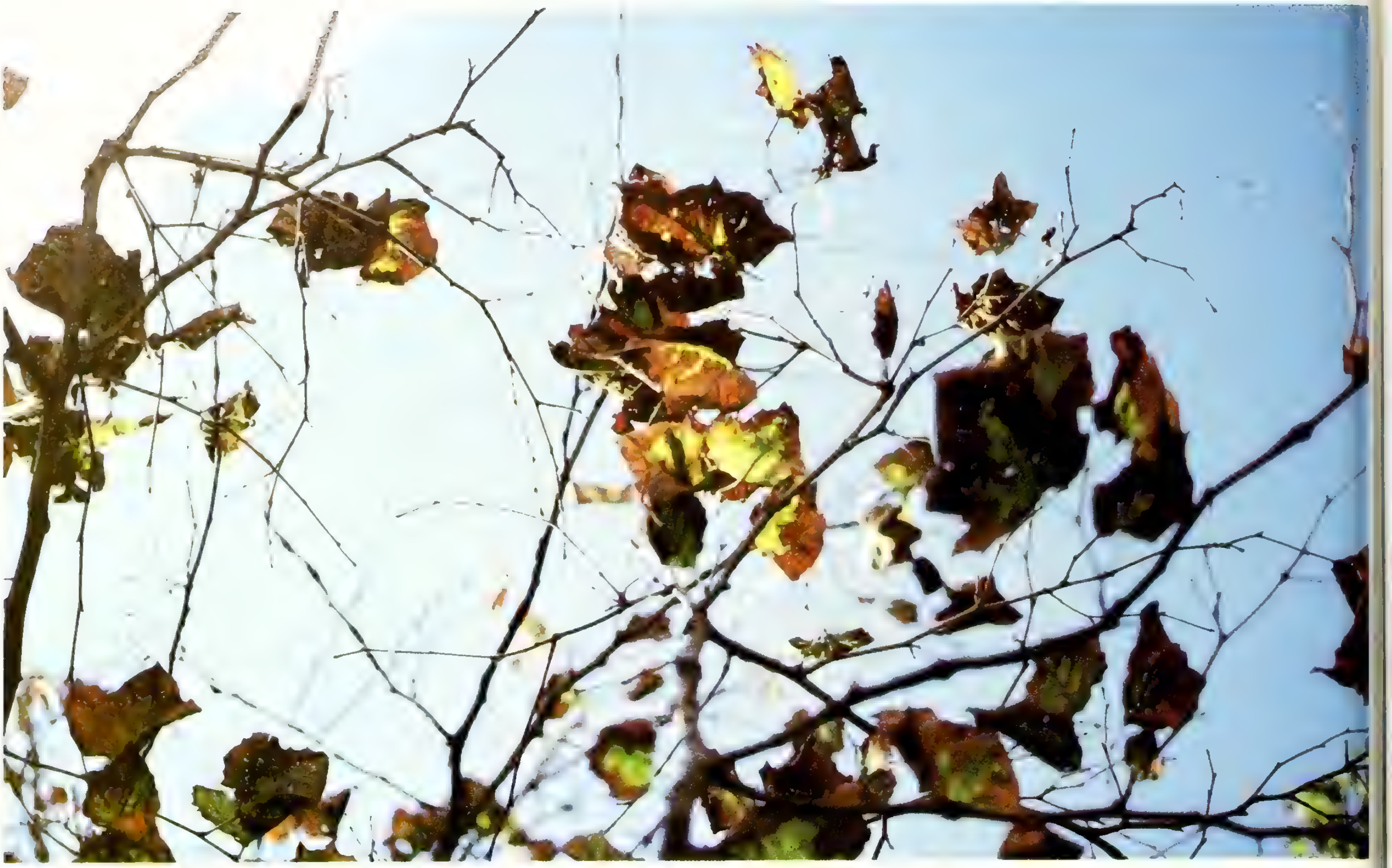


Figure 7-5. Leaf necrosis and twig dieback of sycamore caused by *Gnomonia platani.*

Disease Cycle

The life cycles of these anthracnose fungi are similar and may be typified by *G. platani*, which attacks sycamore (figs. 7–5, 7–6). The fungus survives the winter in infected twigs and branches on the tree and on fallen infected leaves and branches. In most situations there is abundant inoculum for infection if conditions are favorable. Asexual spores (conidia) are the most important stage for dissemination and infection by anthracnose fungi. In several species, the sexual spores (ascospores) may also be produced and serve as primary inoculum; however, their relative importance compared to the conidial stage is undetermined.

Spores are disseminated by wind and splashing rain to buds, shoots, and expanding leaves, where infection begins if conditions are favorable. In some species, infections develop during favorable periods in summer, giving rise to late-season spots or leaf blight.

Damage

Anthracnose fungi cause defoliation and branc dieback, which disfigures the tree. If anthracnose severe for several seasons, the tree may be weakened an start to decline, or may become susceptible to oth diseases or insect pests. Trees stressed by root restri tion, drought, heavy scale infestation, etc., are much le tolerant to anthracnose, and may show decreased vig after only a single season of severe anthracno defoliation.

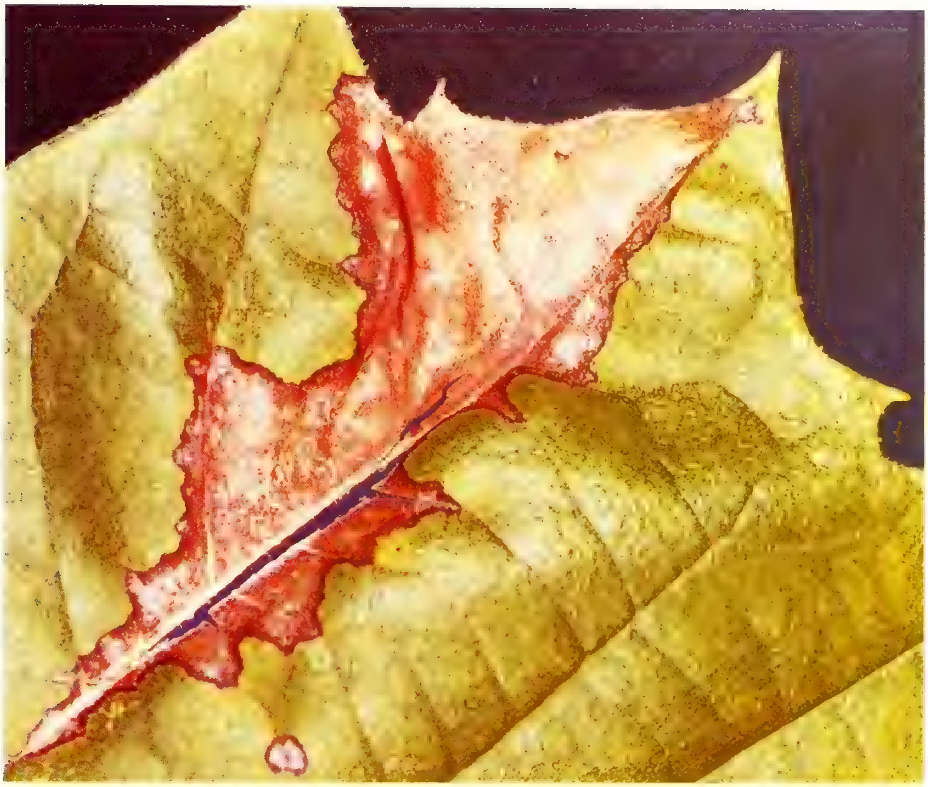


Figure 7-6. Leaf necrosis of sycamore caused by *Gnomonia platani*.

ontrol

Because individual trees vary in susceptibility to anhracnose, there is potential for selection of resistant lones or seed sources of highly resistant trees. The true ondon plane-tree (an inter-specific hybrid) is much less usceptible than the native American sycamore. Oaks in he white oak group are much more susceptible to anhracnose than those in the red oak group.

Fungicide sprays have long been used in attempts to ontrol anthracnose on boulevard and residential plantngs. Specific protectant fungicides are registered for cerain tree species. Follow label instructions for times of pplication and dosage rates. Specific recommendations n type of spray and timing vary with locality. Consult our local Extension Plant Pathologist or Forester for urrent recommendations for your area. Recently, several systemic fungicides have been registered for tree injection to control anthracnose fungi.

Cultural measures, such as raking up leaves in fall and pruning out infected twigs and branches, reduce spring inoculum, but probably not enough to affect disease development except on isolated young trees.

Selected References

Barr, M. E. The Diaporthales in North America. Mycologia Memoir 7. Lehre, Germany: J. Cramer Publication; 1978.

Cooper, D. T.; Filer, T. H. Jr.; Wells, O. O. Geographic variation in disease susceptibility of American sycamore. Southern Journal of Applied Forestry. 1: 21–24; 1977.

Hepting, George H. Diseases of forest and shade trees of the United States and Canada. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture; 1971. 658 p.

Neely, Dan; Himelick, E. B. Temperature and sycamore anthracnose severity. Plant Disease Reporter. 47: 171–175; 1963.

Neely, Dan; Himelick, E. B. Characteristics and nomenclature of the oak anthracnose fungus. Phytopathology. 57: 1230–1236; 1967.

Snyder, T. E.; Stack, R. W. Occurrence of *Gloeosporium aridum* on green ash at different times of the year. Proceedings North Dakota Academy of Sciences. 37: 95; 1983.

8. Oak Leaf Blister

Kenneth E. Conway and John E. Watkins

Oaks, our most abundant hardwood genus, grow naturally in the eastern and southern Great Plains. They are planted frequently in rural and urban environments as shade trees, and are occasionally used in windbreaks in the northern Great Plains. Oak leaf blister, caused by *Taphrina caerulescens*, is one of the most common leaf diseases of oak.

Hosts and Distribution

Over 90 species of *Taphrina* are recognized; they cause diseases on various hosts. Some of the more widely recognized diseases include peach leaf curl (peach), plum pockets (plum), and leaf blisters (cherry, maple, elm, alder, oak).

Oak leaf blister is a major leaf disease of oaks in the southern United States. Oaks in the red and black subgenus are most susceptible to *T. caerulescens*, but all species of oak are susceptible.

Symptoms and Signs

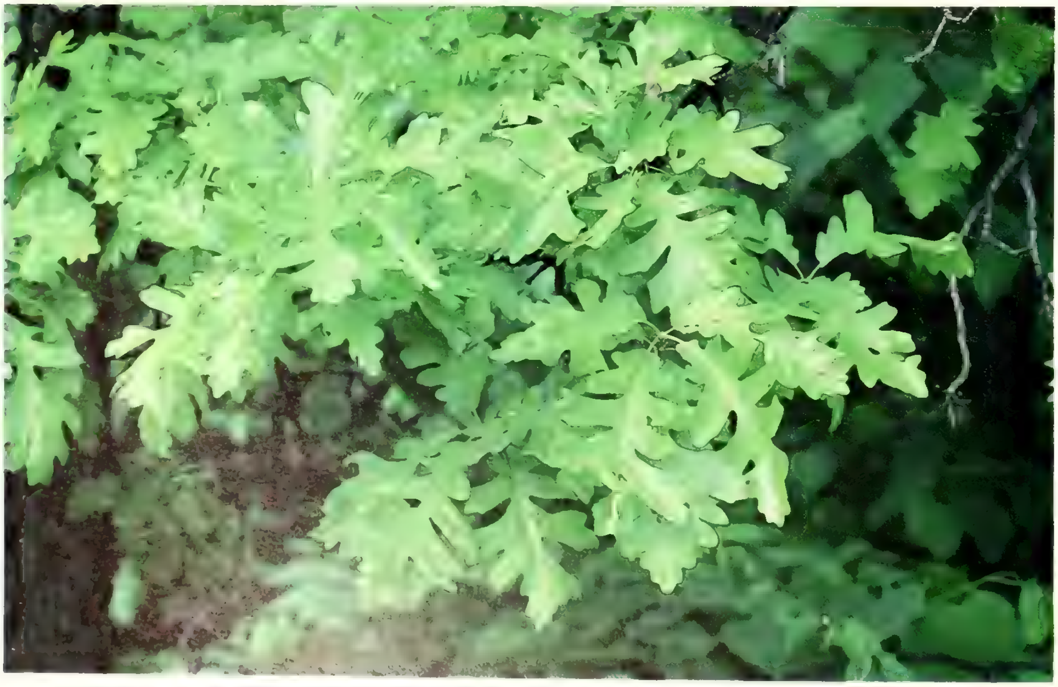
This disease may go unnoticed until a large number of leaves are severely infected or begin to fall. The initial symptom is a slight yellowing of infected leaf tissue followed by formation of circular, raised blisters on th leaves (fig. 8–1). Blisters form when infected cells ar stimulated to enlarge, while surrounding noninfecte cells remain rigid. Blisters are usually less than 1 inc in diameter, and the lower surface will appear gray a the fungus develops in the leaf tissue.

The upper surface of the leaf blister remains light gree for several weeks before dead tissue turns brown. Multiple infections cause a single leaf to become distorte (fig. 8–2). Premature defoliation may occur in the earl fall. The fungus survives, presumably as conidia, on bu scales and in bark crevasses.

Disease Cycle

No fruiting structure is formed by *T. caerulescens* Leaves are infected in early spring by conidia forme from ascospores during the previous season. Myceliu ramifies through the leaf tissue intercellularly an becomes massed just below the cuticle, where it eventually fragments into thick-walled binucleate cells. Th upper portion of these cells becomes an ascus and eigh ascospores are formed. As the asci form, pressure is ex

Figure 8-1. Distorted oak leaves showing mild symptoms caused by *Taphrina caerulescens*.



ed on the cuticle, and the asci eventually break rough to form a compact layer on the epidermis of the st (fig. 8–3). Ascospores bud in the ascus to produce nidia or are released intact from the ascus. Released cospores then bud to form conidia. The conidia reside bud scales and in bark crevasses, and spread to suscep- ble leaf tissue by rain where they produce germ tubes at infect leaves the following spring as the leaf buds gin to develop.

amage

Heavy infections occur following cool, wet springs and ay result in 50 to 85 percent defoliation of affected trees midsummer. Defoliation can reduce growth and, if peated over a period of years, may weaken the tree so at it is susceptible to attack by other organisms.

ontrol

Chemical control of oak leaf blister is not normally commended for forest or shade trees. The disease may unsightly and cause much anguish to homeowners, t vigorous trees are not severely affected. Particular- valuable trees may warrant treatment with fungicide, hich must be applied as dormant spray to be effective. ngicides are not effective after leaves begin to develop cause infection has already occurred. Collecting and sposing of infected leaves will remove some inoculum. aintenance of trees in healthy condition by fertiliza- on, watering, pruning, and insect control will reduce e effect of this disease.

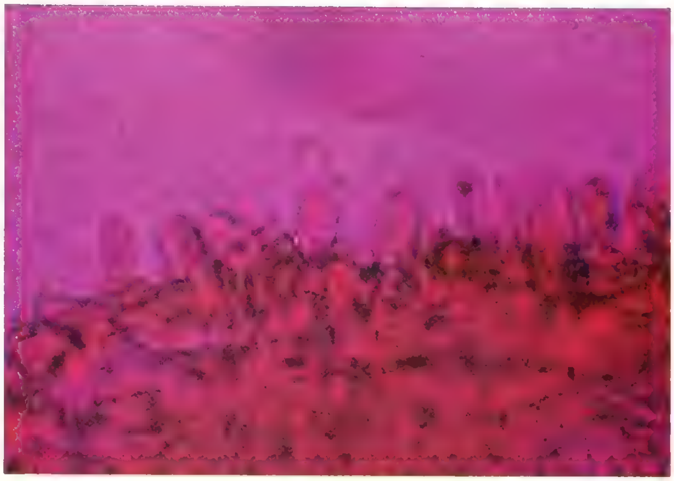


Figure 8-3. Cross section of a leaf blister showing a compacted layer of asci of *T. caerulescens* on the upper surface of a leaf.

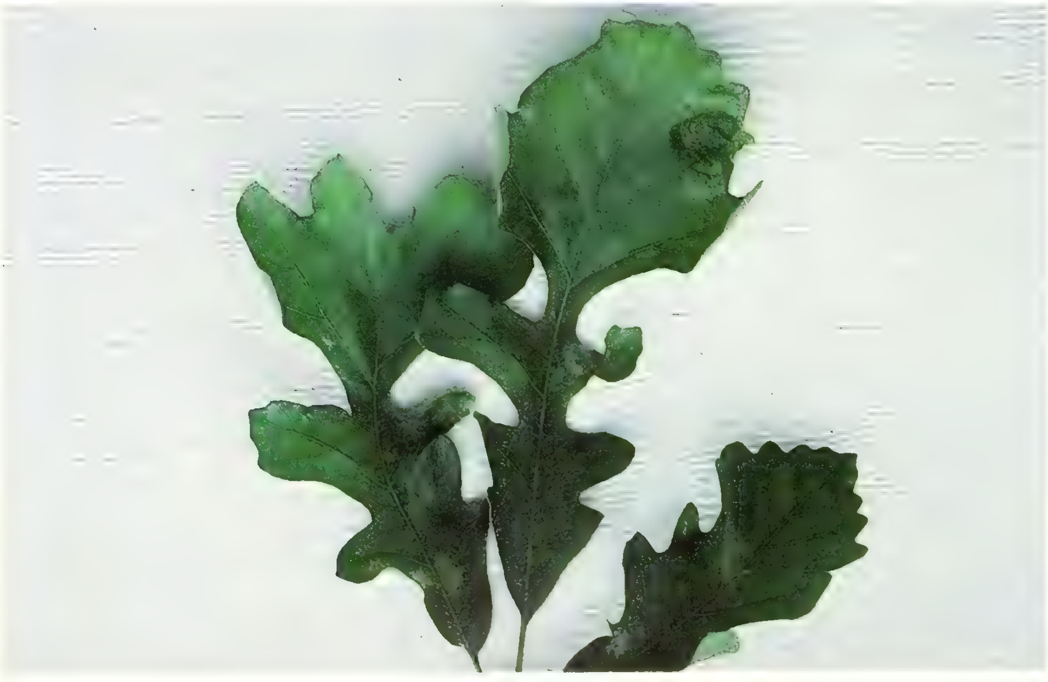
Selected References

Kramer, C. L. Protomycetales and Taphrinales. In: The fungi. An advanced treatise. Vol. IV A. Ainsworth, G. C.; Sparrow, F. K.; Sussman, A. S., eds., New York: Academic Press; 1973: 33–41.

Mix, A. J. A monograph of the genus *Taphrina*. University of Kansas Science Bulletin. 33: 3–167; 1949.

Skelly, J. M. Leaf diseases of hardwood. Forest tree diseases of Virginia. Extension Circular MR–FTD–16. Richmond, VA: 1972.

Figure 8-2. Blistered and distorted leaves of bur oak caused by *T. caerulescens.*



9. Leaf Spots of Nanking Cherry and Chokecherry

Robert L. James and John E. Watkins

Leaf spots are common diseases of Nanking cherry and chokecherry in the Great Plains. Chokecherry is often planted in windbreaks; Nanking cherry, a common ornamental, is also planted occasionally in windbreaks.

Hosts and Distribution

Nanking cherry and chokecherry leaf spots are caused by the fungus *Coccomyces hiemalis* (often referred to as *C. lutescens* on chokecherry) and the bacterium *Pseudomonas syringae* pv. *syringae*. Both pathogens produce typical "shot-hole" lesions, a common name of the disease. These diseases are common throughout the range of their hosts and are particularly important in the Great Plains and eastern United States. *C. hiemalis* also causes a serious disease of commercial cherries, particularly in the Lake States. *Pseudomonas syringae* pv *syringae* also causes leaf spots and cankers of commercial stone fruit trees.

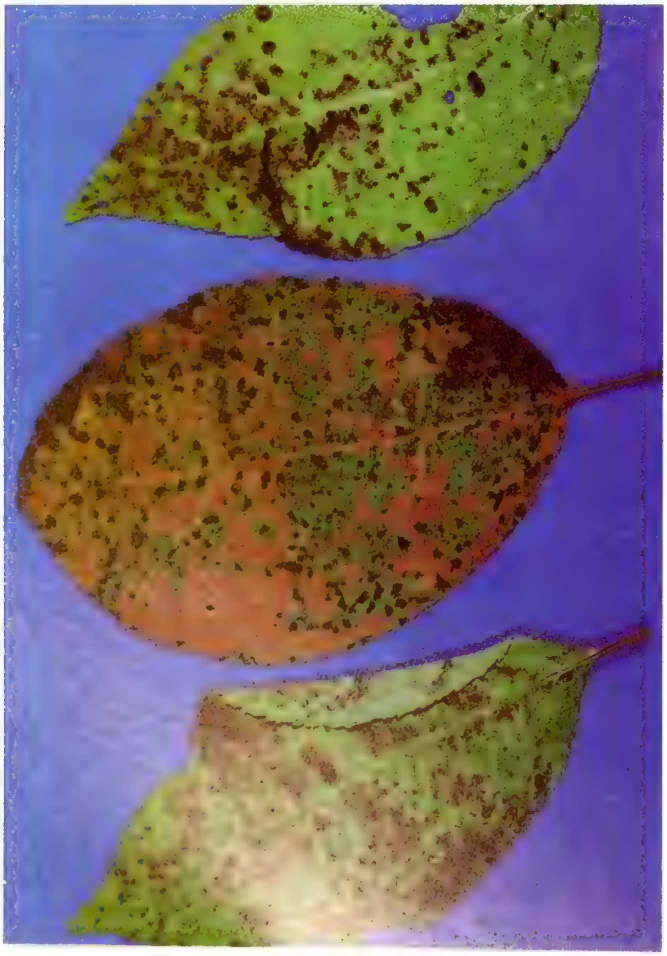


Figure 9-1. Leaf spot symptoms on chokecherry caused by *Co comyces hiemalis.*

Symptoms and Signs

Leaf spots caused by C. *hiemalis* first appear as small purple or reddish circular spots, which later enlarge and turn brown. Spots are usually 4–5 mm in diameter; they may be few in number or become so numerous as to coalesce and form large irregular necrotic areas (figs. 9–1 9–2). During humid periods, whitish spore masses (conidia) are visible in the center of lesions; these masses are more numerous on the underside of leaves. Generally necrotic tissues within lesions separate from the surrounding leaf tissues, forming characteristic shot-holes During severe stages of disease, infected leaves become highly chlorotic, and trees may appear yellow. Premature defoliation of heavily infected trees may occur.

The leaf spots caused by *P. syringae* pv. *syringae* are similar. Lesions are reddish-brown, angular or circular and frequently fall out, giving infected leaves a tattered appearance. Lesions may coalesce to form large areas of necrotic tissue. Heavily infected leaves are chlorotic and may be shed prematurely. *P. syringae* pv. *syringae* also may cause depressed black lesions on fruits, and cankers on twigs and branches. Gummosis commonly occurs around cankers.

Disease Cycle

Infection by C. *hiemalis* begins in the spring, and is caused by ascospores from fruiting bodies (apothecia that form on previously infected, fallen leaves Ascospores are wind dispersed and cause infection during April and May. Leaves are especially susceptible

ortly after budbreak. The conidial stage of the fungus
lindrosporium sp.) forms white spore masses within
center of leaf lesions. Conidia are dispersed by rain
d cause secondary infections throughout the summer.
rm temperatures are especially conducive to disease
velopment. Heavy infection may cause premature leaf
l; some trees may be completely defoliated by July.
peated infections reduce tree vigor.

. *syringae* pv. *syringae* is a common epiphyte and
en occurs on the fruit, limbs, and leaves of both
sceptible and nonsusceptible plants. Infection is cor-
ated more closely with favorable weather conditions
an with the availability of inoculum. Bacteria over-
nter within cankers and are spread to and cause in-
tion of leaves in the spring during cool, wet weather.
ee-standing water is necessary for leaf infection.
nkers are formed when bacteria infect branches
rough wounds, such as those made during pruning.
peated infections develop throughout the growing
ason during wet periods. Heavily infected leaves fall
ematurely. Trees with repeated infections decline over
veral years.

amage

C. hiemalis causes serious damage to commercial cher-
s in parts of the United States and Europe. Effects on
anking cherry and chokecherry are less dramatic,
though plantings of chokecherry have been reduced in
rts of the Great Plains because of this disease. The
thogen commonly causes severe defoliation of choke-
erry in Great Plains nurseries. *P. syringae* pv. *syringae*
most important as a canker-causing pathogen of com-
ercial stone fruit trees. Its effect on Nanking cherry
d chokecherry is limited, although some windbreak
d ornamental plantings may be severely infected. Both
seases reduce vigor of trees but rarely kill them.

ontrol

Usually, control of these leaf spot diseases is necessary
ly in commercial fruit growing areas and in nurseries.
hiemalis can be controlled with protectant fungicides
plied directly to foliage, or with eradicant fungicides
plied on previously infected leaves on the ground
out the time apothecia are swelling. Best results have
en obtained with several foliar applications of fungi-
des coordinated with periods of high infection hazard.

A model has been formulated recently which predicts periods of high disease probability in commercial cherry orchards. The number of fungicide applications necessary to control the disease has been reduced by use of this model.

Leaf spot caused by *P. syringae* pv. *syringae* can be controlled by sanitation, such as dormant pruning of cankered wood and removal of leaves and other debris in the fall. Fungicides can be used to suppress disease development, but fungicides alone do not provide good control. A combination of sanitation and fungicide application is recommended.

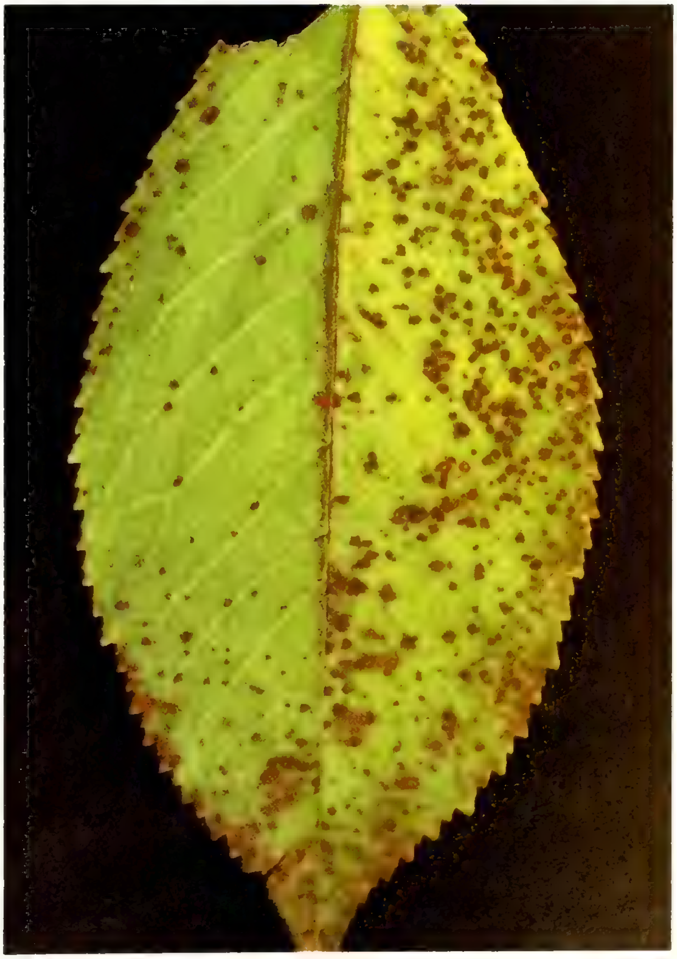
Selected References

Cameron, H. R. Mode of infection of sweet cherry by *Pseudomonas syringae*. Phytopathology. 52: 917–921; 1962.

Eisensmith, S. P., R. Loria, B. D. Olson, and A. L. Jones. 1980:EPISTAR: An epidemiological information storage, retrieval, and analysis system. Plant Disease 64: 646–651.

Heald, Frederick Deforest. Manual of plant diseases. New York: McGraw-Hill; 1933. 953 p.

Inman, R. E.; Weihing, J. L. Cyprex: a superior control for shothole disease of chokecherry. Plant Disease Reporter. 43: 536–539; 1959.



gure 9-2. Leaf spot symptoms on sweet cherry caused by *C. hiemalis*.

10. Western X-Disease of Chokecherry

Glenn W. Peterson and David W. Johnson

Chokecherry is used as a shrub in windbreaks and as a component of wildlife plantings in the central and northern Great Plains. Chokecherry in many of these plantings is infected by the western X-disease pathogen (fig. 10–1).

Hosts and Distribution

The western X-disease pathogen infects chokecherry, sweet and sour cherries, several varieties of peach, and some other *Prunus* species. American plum has been infected by inoculations; however, after 9 years there were no visible symptoms on American plum interplanted among infected chokecherry in eastern Nebraska.

The disease is present in the northern and central Great Plains (Wyoming, North Dakota, South Dakota, and Nebraska).

Symptoms and Signs

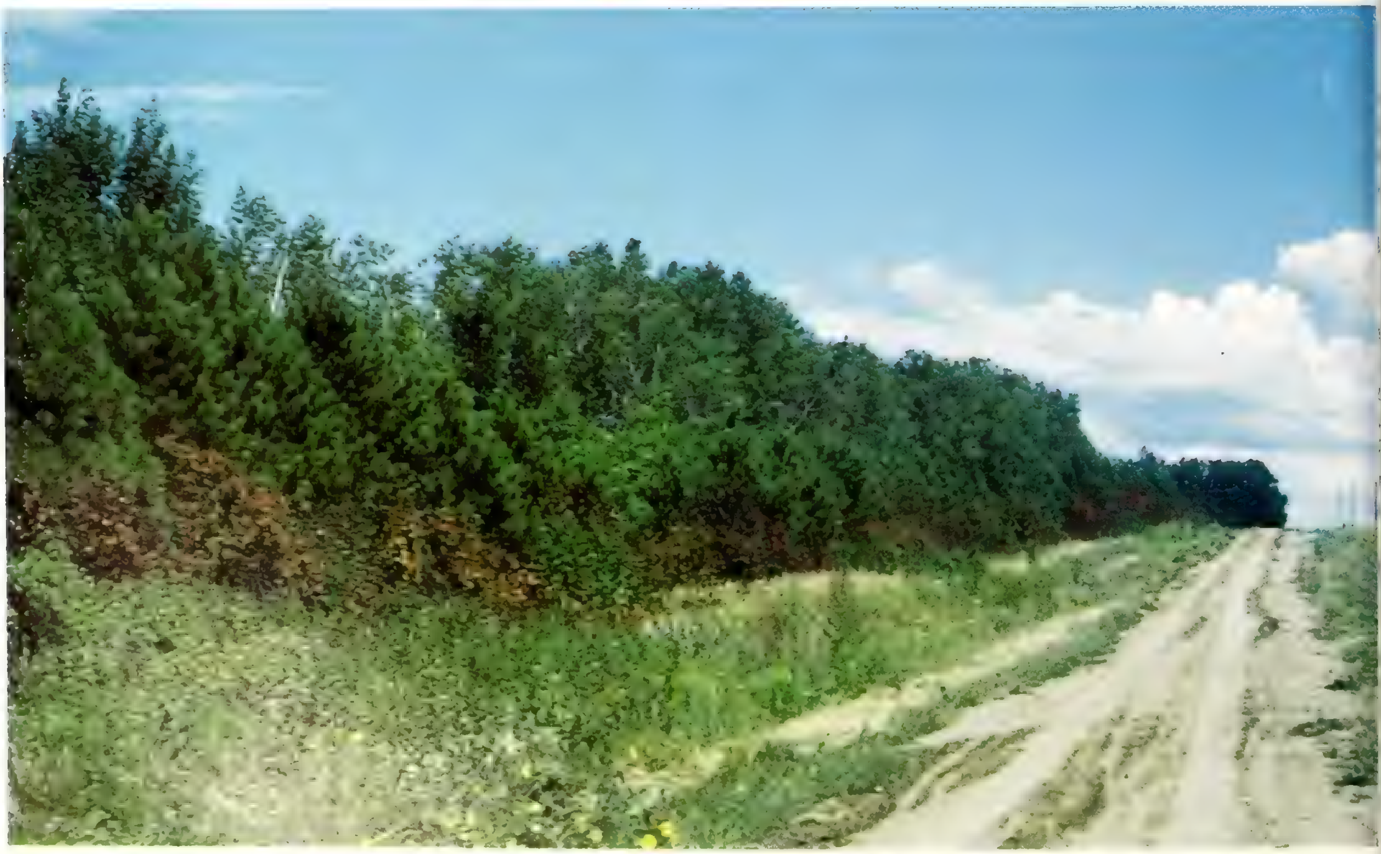
Infected leaves become greenish-yellow in late Jun These leaves may have a reddish tinge on their border In July and August the leaves turn deep red (figs. 10– 10–3). Shoots are stunted, and rosettes result fro shortened internodes at the tip. Infected fruits a somewhat pointed and are yellowish-red, not the norm deep red of healthy fruit. Both diseased and healthy frui may be found on the same tree.

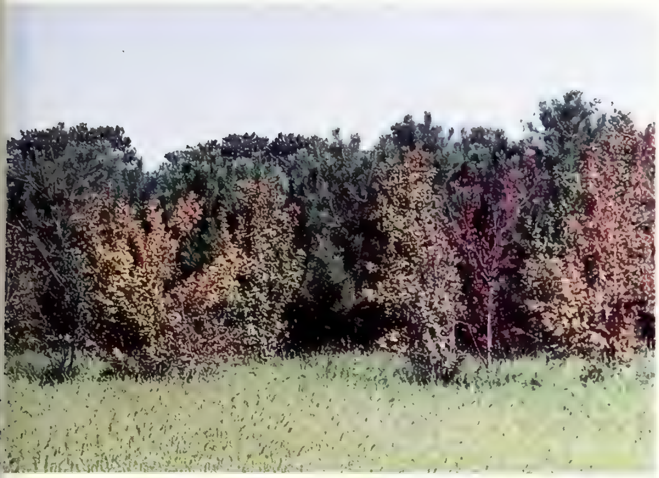
Disease Cycle

The western X-disease pathogen for many years w thought to be caused by a virus; however, the disease caused by a spiroplasma.

The western X-disease pathogen is transmitted

Figure 10-1. Infected chokecherry along length of windbreak.





igure 10-2. Western X-disease symptoms, several trees.

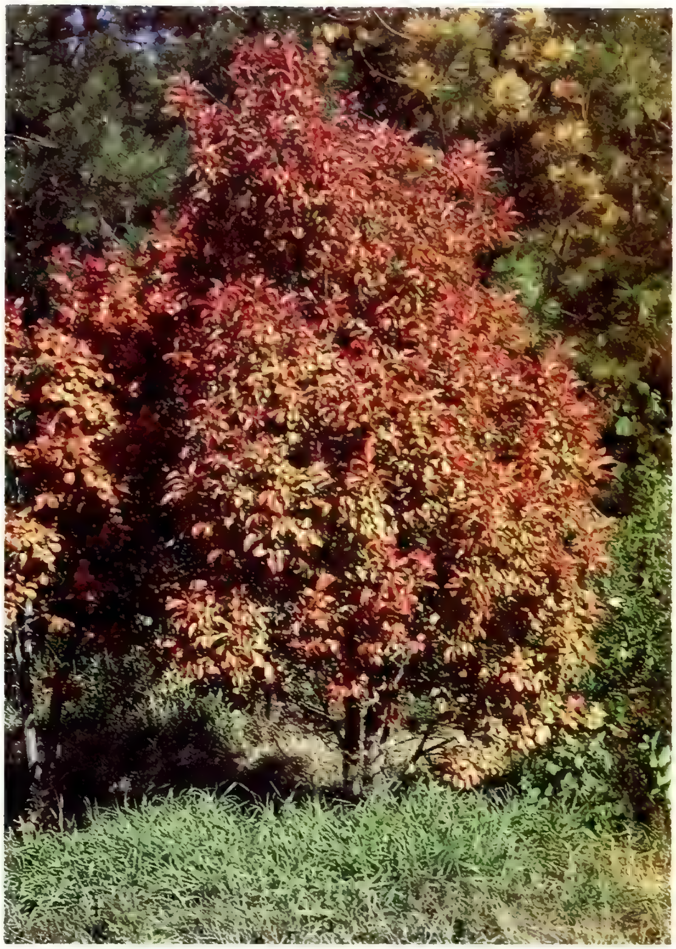


Figure 10-3. Symptoms, single tree.

runus hosts by *Colladanus geminatus, C. montanus,* and ther leafhoppers when they feed on the leaves. Symp-oms on leaves usually do not develop until the growing eason following the year of transmission.

amage

Growth of infected chokecherry is reduced, internodes ecome shorter, the shrubs gradually decline, and ltimately die. In eastern Nebraska, symptoms appeared n more than 80 percent of the chokecherries within 3 ears after the X-disease pathogen was introduced; mor-ality was more than 50 percent within 8 years. Infected ruits are not suitable for use in jams and jellies, and their eeds do not germinate.

ontrol

Nurseries should avoid establishing beds of choke-herry near *Prunus* species that are hosts of the patho-en. Because the pathogen spreads rapidly from infected o healthy shrubs, new plantings of chokecherry should ot be established near infected chokecherry.

Because American plum has been infected following rtificial inoculation with the pathogen, it could possibly be a symptomless carrier and thus a threat to chokecherry, but there is no supporting evidence.

Thus, American plum can be included in plantings containing chokecherry with confidence that the X-disease pathogen will not seriously damage it.

Selected References

Gilmer, R. M.; Moore, J. Duain; Keitt, G. W. X-disease virus: I. Host range and pathogenesis in chokecherry. Phytopathology. 44: 180–185; 1954.

Granett, A. L.; Gilmer, R. M. Mycoplasmas associated with X-disease in various *Prunus* species. Phytopathology. 61: 1036–1037; 1971.

Peterson, Glenn W. Western X-disease virus of chokecherry: transmission and seed effects. Plant Disease Reporter. 50: 659–660; 1966.

Peterson, Glenn W. Spread and damage of western X-disease of chokecherry in eastern Nebraska plantings. Plant Disease. 68: 103–104; 1984.

Rosenberger, D. A.; Jones, A. L. Leafhopper vectors of the peach X-disease pathogen and its seasonal transmission from chokecherry. Phytopathology. 68: 782–790; 1978.

11. Honeysuckle Leaf Blight

Jerry W. Riffle and John E. Watkins

Honeysuckle has been commonly used in windbreak and landscape plantings in the northern Great Plains. Demand for hardy shrub species is high, but production of honeysuckle is hampered by frequent epidemics of honeysuckle leaf blight and other pests. This blight is caused by *Insolibasidium deformans*. This pathogen is listed as *Herpobasidium deformans* in papers published before 1984.

Hosts and Distribution

Most species and varieties of native and introduced honeysuckle are hosts of *I. deformans*. Amur honeysuckle has shown some resistance to the pathogen in a nursery in Iowa. The disease is widespread in northeastern and northcentral U.S., and occurs in North Dakota, South Dakota, Nebraska, Minnesota, Iowa, Wisconsin, Michigan, Indiana, Ohio, Pennsylvania, New York, Massachusetts, Connecticut, and Rhode Island.

Symptoms and Signs

This disease appears in the spring on newly emerging leaves. The first symptom is a yellowing of infected veinlets and of leaf tissues bounded by veinlets. These tissues become tan to brown and finally necrotic and dry, with brown areas involving an entire leaf or a large portion of it (fig. 11–1). The leaves are often rolled and twisted (fig. 11–2) and drop prematurely. The first sign of the pathogen is a thin, white layer of basidia and

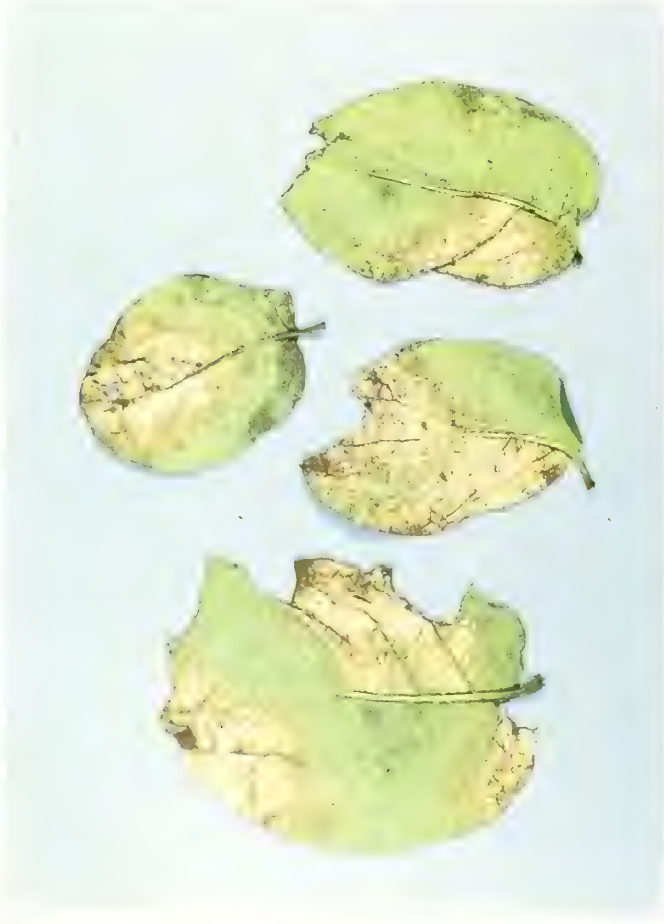


Figure 11-1. Lower surfaces of honeysuckle leaves infected with *Insolibasidium deformans* and showing tan to brown necrotic areas involving large portions of leaves.

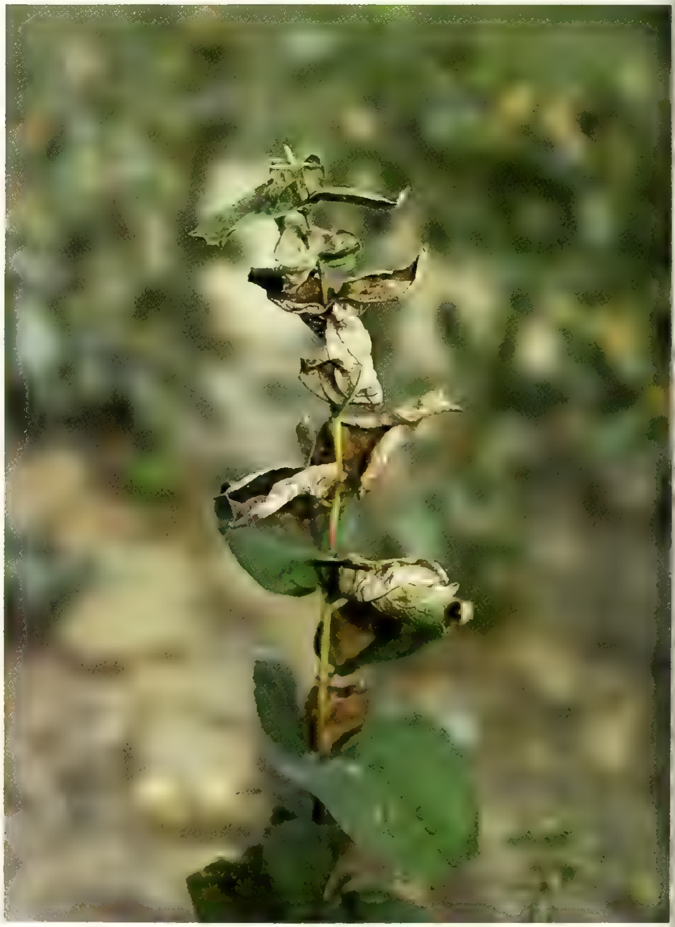
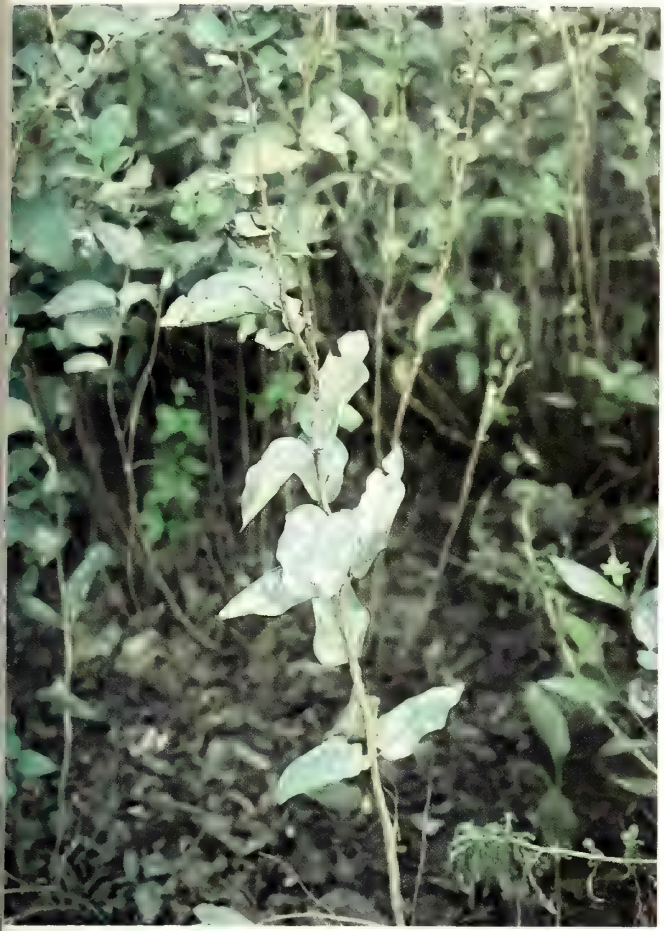


Figure 11-2. Honeysuckle seedlings infected with *I. deforman* show curled, rolled, and discolored leaves.



igure 11-3. Honeysuckle seedling infected with powdery mildew fungus.

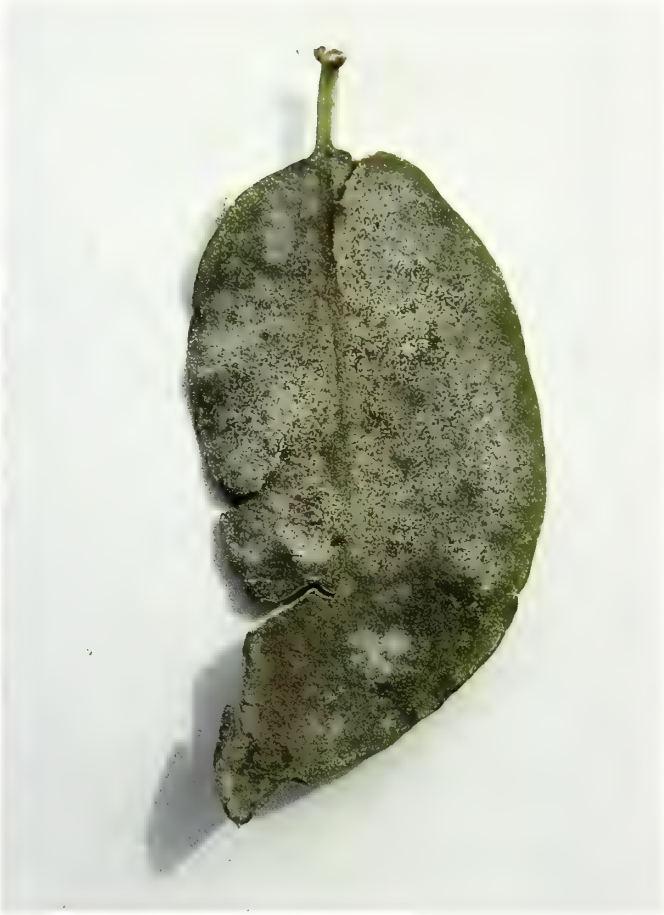
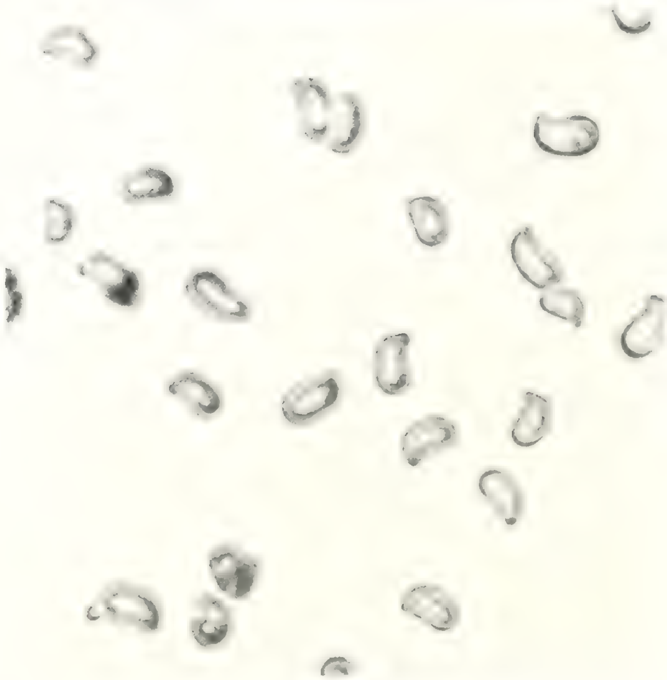


Figure 11-4 Honeysuckle leaf with numerous black fruiting bodies of powdery mildew fungus on upper surface.

asidiospores on the lower leaf surface, often followed y a white powdery mass of conidia. Powdery mildew ungus can be distinguished from *I. deformans* by white owdery mildew mycelia and black fruiting bodies that evelop principally on the upper surface of nonrolled eaves in late summer (figs. 11–3, 11–4).

Two spore stages may be found on diseased leaf issues. Mature basidiospores arise from curved, ransversely septate basidia emerging through stomates rom hyphae in the leaves. Basidiospores are hyaline, ninucleate, cylindrical with rounded ends except for n apiculus at the attached end, and measure 9–13 by –7.5 μm (average 10.9 by 6.6 μm) (fig. 11–5). They have een found commonly throughout the growing season n nursery beds containing infected stock. Conidia fre- uently develop in or near the area of basidial formation n the lower leaf surface. They occur less commonly han basidiospores and are difficult to find. Conidia are –17 μm in diameter, globose, hyaline, warty, binucle- te, and form three pairs to a cluster (fig. 11–6). The outer airs are usually the only spores to germinate. The func- ion of conidia is unknown; they are presumably resting pores.

Figure 11-5. Basidiospores of *I. deformans*.



I. deformans overwinters as mycelium or basidiospores in dead leaves. Basidiospores serve as primary inoculum for infection of developing leaves of the first foliage flush, and also for secondary infections during the remainder of the year. Infection of leaves is intensified when the temperature is 59° to 64° F, the relative humidity is near or at 100 percent in sustained periods for at least 2 days, and leaves are less than 20 days old. Below-normal temperatures and high humidity in August and September enhance disease development, which results in premature loss of foliage and growth reduction.

Damage

Epidemics have increased in frequency in central and northern Great Plains nurseries since 1960. When blight is severe, most seedlings in nursery beds become infected and defoliate prematurely (fig. 11–7). Severe defoliation results in stem dieback and reduced growth, and stock may have to be retained in the nursery an additional year. Fifty percent or more of plantable seedlings have been lost in at least one northern Great Plains nursery even after seedlings were held for an additional year. Such losses also disrupt planned nursery stock inventories because seedbeds are used for an additional year.

No information is available on extent of damage to honeysuckle in windbreak and landscape plantings.

Control (Cultural)

Honeysuckles in landscape, windbreak, and nursery plantings may become infected; thus they should not be used in nursery windbreaks or in other plantings on nursery grounds because they may be a source of *I. deformans* inoculum for nursery seedlings.

Seedlings grown at high densities in seedbeds develop dense foliage that reduces aeration and increases humidity, conditions that favor disease development. Where possible, reduce seedbed density or grow seedlings as row crops to improve aeration and reduce humidity. Irrigation should be scheduled so that periods of high moisture and free water in and around foliage and stems are as short as possible. Any cultural practice that destroys or removes overwintering foliage from seedbeds will reduce inoculum sources.

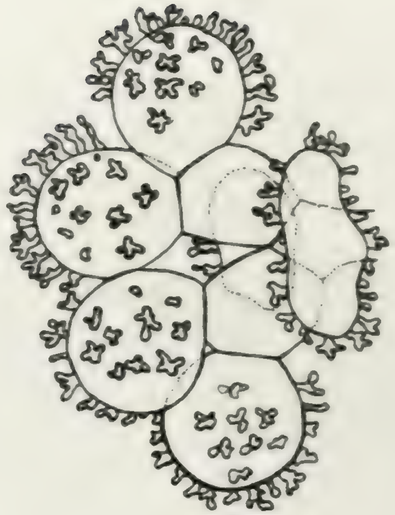


Figure 11-6. A cluster of three pairs of *I. deformans* conidia.

Control (Chemical)

A regular protective spray program will minimize th
risk of disease damage. Seedlings need protection du
ing the entire growing season because basidiospores a
dispersed throughout the period. Protectant fungicid
must be applied frequently to protect newly developi
susceptible foliage. Mancozeb (Fore^{R} turf and ornamе
tal fungicide) is registered for control of *I. deformans*
honeysuckle. Use 1.5 pounds per 100 gallons of wat
in full coverage spray to point of runoff. Begin sprayi
when seedlings are leafed-out and apply at 7- to 10-d
intervals throughout the season. Chlorothalonil (Daco
2787^{R}), applied at 2 quarts per 100 gallons of water p
acre gave best control of *I. deformans* on tatari
honeysuckle among seven fungicides tested in an Io
nursery in 1984. Fungicides used for control of *I. def*
mans in nurseries may be effective for control of th
pathogen in windbreaks and landscapes.

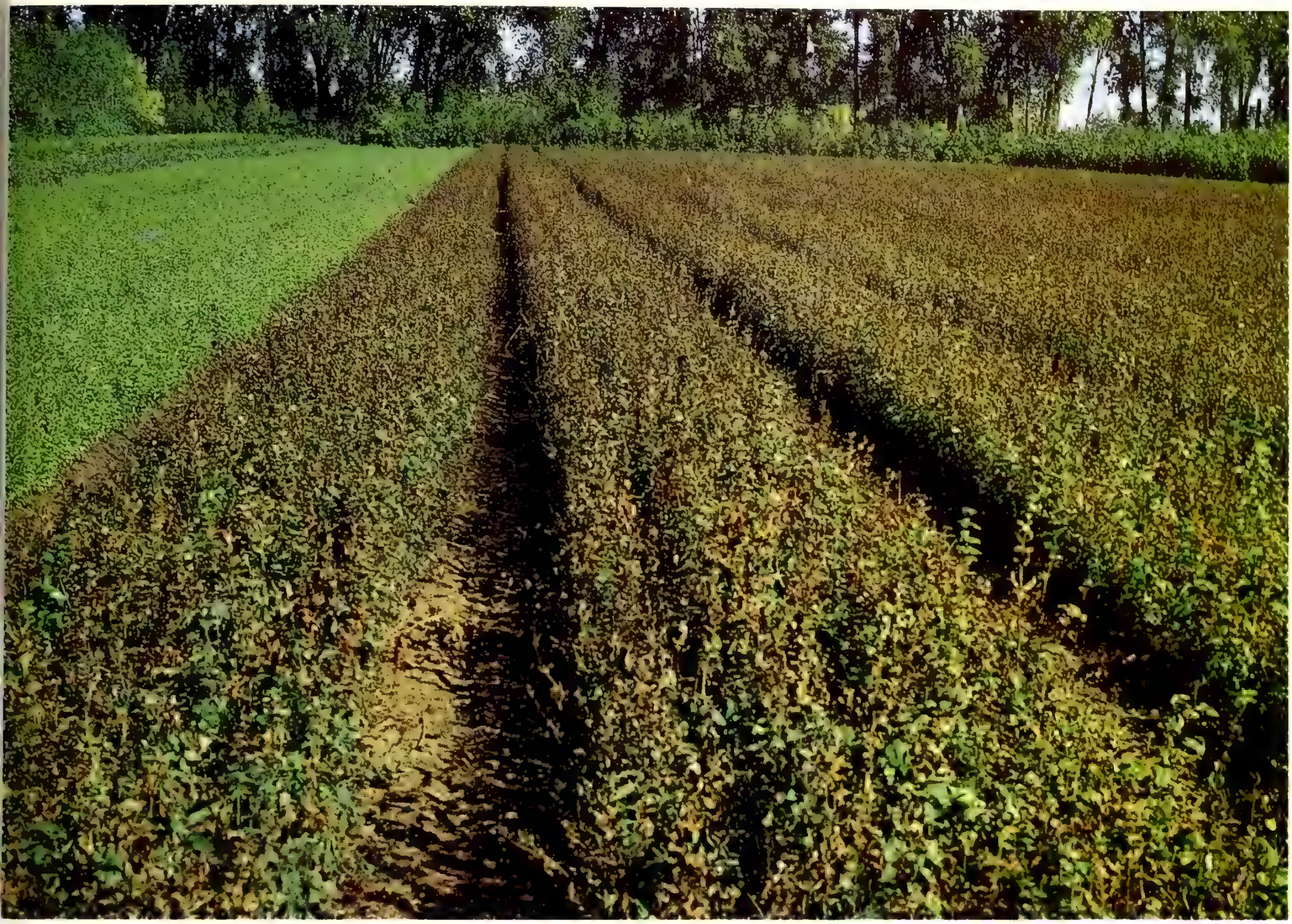


Figure 11-7. Nursery beds containing 2-year-old honeysuckle seedlings infected with *I. deformans.*

Selected References

Gould, Charles J., Jr. The parasitism of *Glomerularia lonicerae* (Pk.) D. and H. in *Lonicera* species. Iowa State College Journal of Science. 19: 301–331; 1945.

Oberwinkler, F.; Bandori, R. *Herpobasidium* and allied genera. Transactions British Mycological Society. 83: 639–658; 1984.

Riffle, Jerry W. Recovery of *Herpobasidium deformans* basidiospores from *Lonicera tatarica* leaves overwintered in nursery beds. (Abstract) Phytopathology. 71: 251–252; 1981.

Sweets, Laura E.; Croghan, Catherine F. Evaluation of fungicides for honeysuckle leaf blight control on Tatarian honeysuckle, 1984. American Phytopathological Society; Fungicide and Nematicide Tests. 40: 205; 1985.

12. Powdery Mildew of Lilac

Richard Dorset and Michael W. Ferguson

Lilacs (*Syringa* spp.) are planted throughout the Great Plains. Most varieties sprout readily from roots, creating dense thickets that make lilac valuable for use in windbreaks, especially in the central and northern Great Plains.

One of the few pathogens that infects and damages lilacs is *Microsphaera alni,* which causes powdery mildew of lilac foliage.

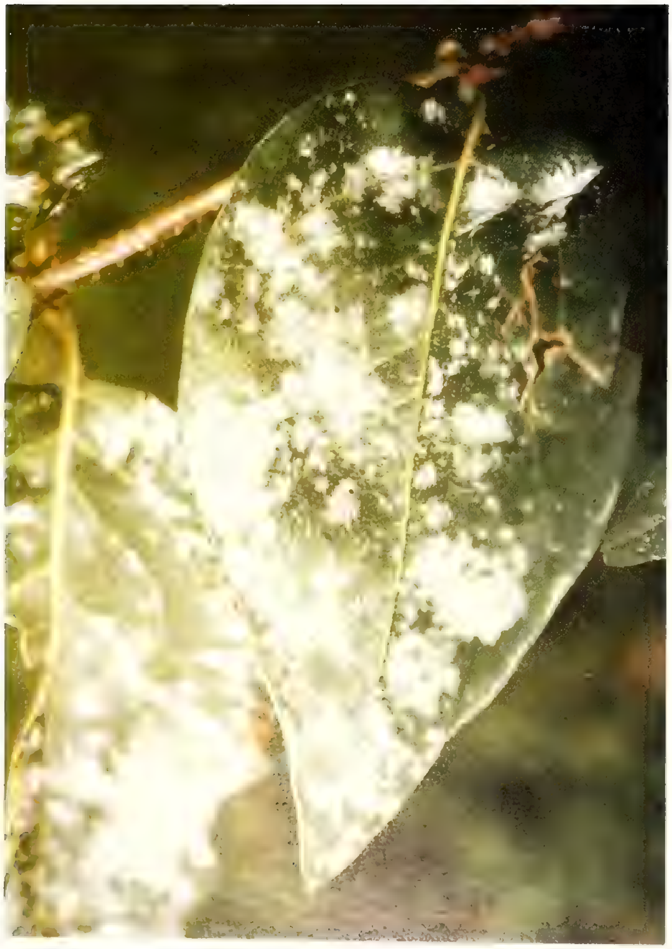
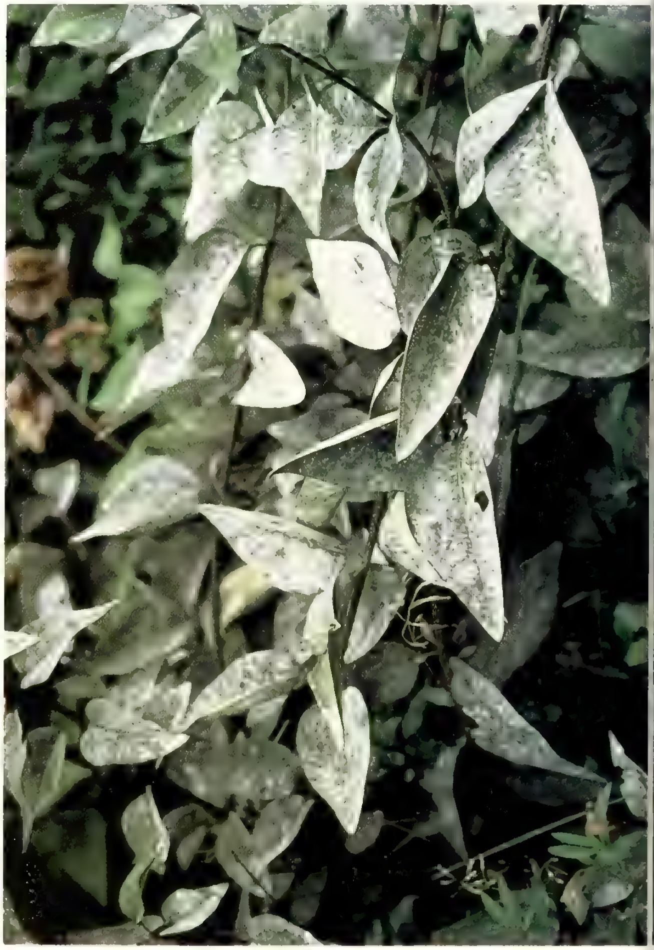
Hosts and Distribution

Powdery mildew fungi infect most species of deciduous woody shrubs and trees. Some are highly specific, infecting only one host, while others have a wide host range. *M. alni* infects not only lilac but a large variety of plants, including alder, birch, hornbeam, hophornbeam, chestnut, holly, maple, hickory, golden chinkapin, beech, honeylocust, walnut, sycamore, oak, elm, ar basswood. With such a wide host range, the fungus distributed throughout the Great Plains.

Even though powdery mildew fungi can infect mo species and varieties of lilac, there is a considerab range of host susceptibility.

Symptoms and Signs

During mid-summer, leaves develop small white gray dusty-looking patches. These patches enlar throughout the summer, and by early fall the entire le surface may be covered with a white powdery-looki substance (figs. 12–1, 12–2). Later in the fall, sm pinpoint-sized brown to black structures devel throughout the powdery areas. These are the sexu fruiting bodies of the fungus.

Figures 12–1, 12–2. Lilac leaves infected by powdery mildew fungus.

Microscopically, the white powder consists of fungus ycelium and asexual spores (fig. 12–3). The sexual uiting bodies, called cleistothecia, have numerous lender appendages that are dichotomously branched at e tips. Several asci are contained in each cleistoecium.

isease Cycle

The pathogen overwinters in fallen leaves as partially eveloped ascospores (fig. 12–4). These spores mature uring wet spring weather, and are then exuded from he black fruiting bodies. These spores are blown or plashed onto non-infected foliage. After germination, austoria of the fungus penetrate the leaf tissue and are estricted to a single layer of cells, the palisade layer. Mycelium growing on the leaf surface produces asexal spores, which are powdery white. These asexual pores are dispersed by wind and rain to other leaves, tarting new infections.

The fungus grows best during warm, damp, summer veather. At the onset of cool weather, growth slows or eases and the sexual fruiting bodies are produced; they verwinter on dead leaves.

amage

Powdery mildew fungi seldom cause enough damage o warrant control measures. However, when infection s extensive, the unsightly appearance caused by these ungi is often severe enough that homeowners may wish o attempt control. Extensive infections occur in late fall ust before the leaves drop normally, and reduce the esthetic and ornamental values of landscape plants.

Control

The easiest way to control powdery mildew is to prevent its occurrence. The disease is best prevented by using resistant species, cultivars, and varieties. Removal of all dead leaves and leaf pieces in the fall will reduce the amount of primary inoculum during the following spring, thereby reducing the number of initial infections.

The severity of infection can be minimized by providing good air circulation and sunlight. Dense plantings, shady areas, and damp places all favor disease development.

Chemicals can be used to either prevent infection or to control established infections. Chemicals should be applied initially when the new leaves are emerging, and repeated as per label instructions. Sulfur has long been used for control. Bayleton and benomyl are two newer chemicals that are registered for powdery mildew on lilac. Both work systemically and have good residual action. Bayleton is a foliar spray, while benomyl may be used as either a soil drench or foliar spray.

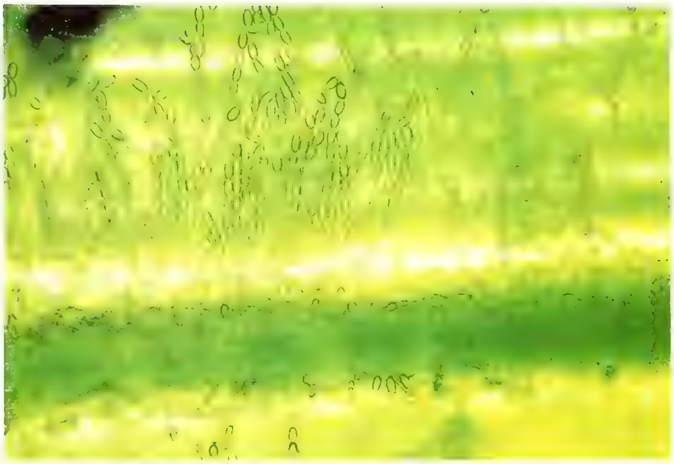


Figure 12-3. Chains of conidia of powdery mildew fungus.

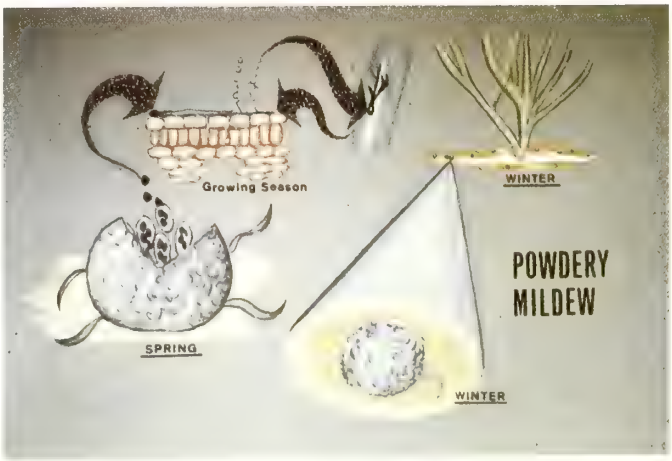
Selected References

Fenicchia, Richard A. Susceptibility of lilacs to leaf curl necrosis and powdery mildew. Plant Propagator. 23(3): 7–13; 1977.

Hepting, George H. Diseases of forest and shade trees of the United States. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture; 1971. 658 p.

Tattar, Terry A. Diseases of shade trees. New York: Academic Press; 1978. 361 p.

Figure 12-4. Life cycle of a powdery mildrew fungus.



13. Cylindrosporium Leaf Spot of Buffaloberry and Skunkbush Sumac

Glenn W. Peterson and Jerry W. Riffle

Buffaloberry (*Shepherdia argentea*) and skunkbush sumac (*Rhus trilobata*) are commonly used in shrub rows in Great Plains windbreaks and in wildlife plantings.

Hosts and Distribution

The leaf spot diseases of skunkbush sumac and buffaloberry were detected in an eastern Nebraska nursery in the early 1960's. The leaf spots are caused by fungi in the genus *Cylindrosporium*. The fungi have not been identified to species; however, they are similar to *Cylindrosporium* species that have been described on other *Rhus* and *Shepherdia* species. *C. toxicodendri* has been found on *R. toxicodendron*, *R. trilobata* and *R. diversiloba*; *C. shepherdiae* has been found on *S. canadensis*. The distribution of these fungi in the Great Plains is not known.

Symptoms and Signs

Circular to irregular leaf spots develop on skunkbush sumac; these spots have tan centers and dark borders. Spotted leaves ultimately turn yellow and drop prematurely (fig. 13–1). On buffaloberry, the leaf spots are irregularly shaped, with tan centers and olive borders. Spotted leaves ultimately become necrotic and drop prematurely. Initial symptoms (leaf spots) on both shrub species develop in late May; considerable defoliation of buffaloberry may occur before mid-June.

Disease Cycle

Detailed information on the disease cycle is lacking. The primary source of spores for initial infection in the spring is probably fruiting bodies that have overwintered on fallen leaves. Leaves are initially infected in May. The fruiting bodies (acervuli) form within the leaf spots and produce slender, septate spores which average 32 by 2.5 μm on buffaloberry and 49 by 2.7 μm on skunkbush sumac.

Damage

Nursery production of skunkbush sumac and buffaloberry is hindered by these leaf spot diseases. Infected seedlings grow poorly due to premature defoliation; they often are kept an additional year in the nursery to reach size sufficient for planting. Damage by these fungi is seldom extensive in field plantings.

Control

Captan or maneb provided adequate control of these fungi in tests in an eastern Nebraska nursery. The first application should be made in mid- to late May. Severa applications are necessary to protect newly developing foliage.

Selected References

Peterson, Glenn W. Control of Cylindrosporium leaf spo disease of *Rhus trilobata* and *Shepherdia argentea* seedlings. Plant Disease Reporter. 51: 700–701; 1967

Saccardo, P. A. Sylloge Fungorum. 11: 582; 1895.

Saccardo, P. A. Sylloge Fungorum. 25: 623; 1931.

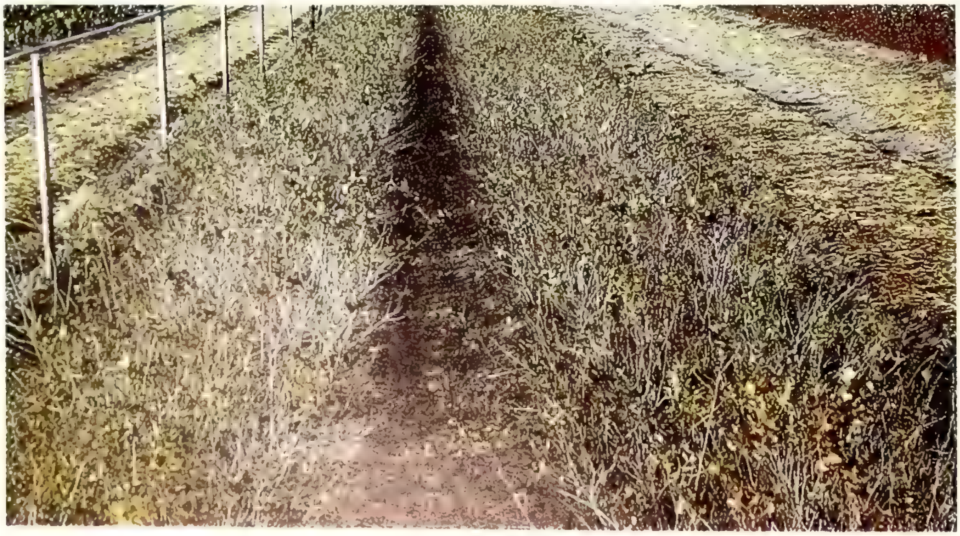


Figure 13–1. Defoliation of skunkbush sumac seedlings caused by *Cylindrosporium* sp.

14. Herbicides (Air Pollution)

Gary A. Boutz and Robert W. Stack

he greatly increased use of herbicides since the l-1950's has also increased the hazard to nontarget etation. Disorders or mortality caused by herbicides particularly prevalent where susceptible tree species le 14–1) are located near crops or areas where herbicides are frequently used. Windbreaks are especially vulnerable to exposure because they are generally located in or around cultivated fields. Trees near right-of-ways, railroads, roadsides, or areas treated for noxious weed control also have a high risk of exposure.

able 14–1. Sensitivity of various tree species to broadleafed weed-killers.

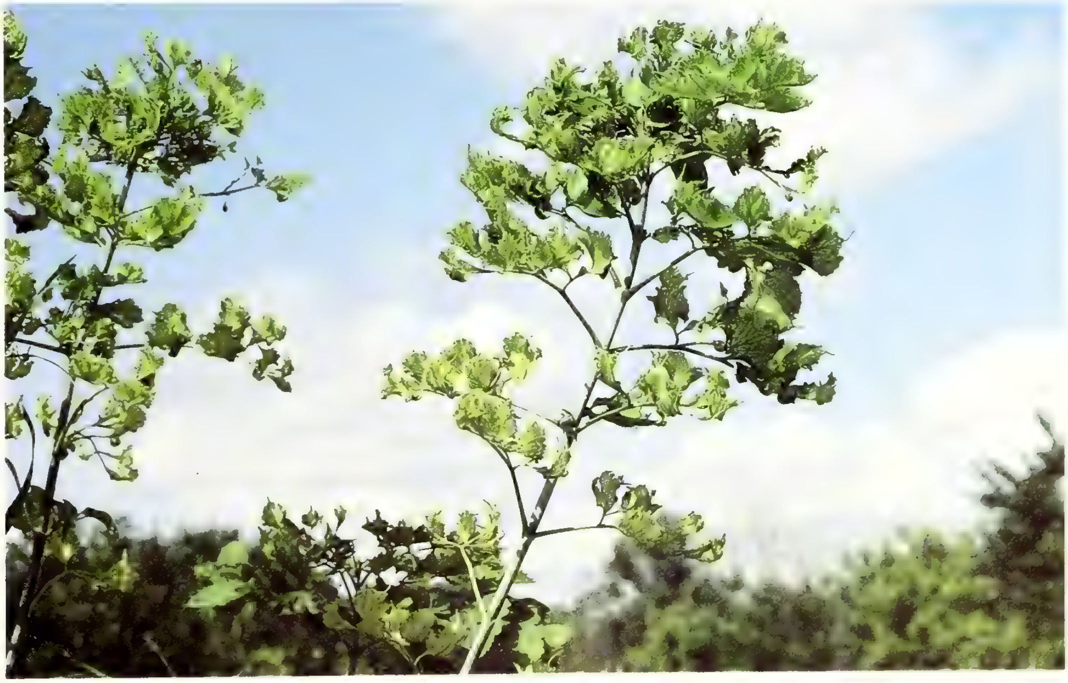
sitive	Intermediate or unknown	Tolerant
elder	mulberry	catalpa
[illegible]	honeylocust	linden
[illegible]	soft maple	pine
kberry	oak	e. redcedar
ur maple	cottonwood	
d maple	cherry	
anthus		
kory		
le		
amore		
bud		
lnut		
ur cork tree		
low		
ch		
sechestnut		

Symptoms

The more common expressions of phenoxy or hormonal-type herbicide injury include cupped leaves, parallel leaf venation on normally net-veined leaves, chlorosis, nastic growth, and wavy or curled leaf margins (figs. 14–1, 14–2, 14–3). Redbud and boxelder are indicator tree species that readily exhibit these effects. Leaves of some trees, such as pin oak, become waxy and stiff, while maples may develop pebbled foliage that appears weather-beaten. Studies with 2,4-D applied to Siberian elm have shown that bark abnormalities may result from relatively heavy exposure. A single 2,4-D exposure may produce injury for 2 years or more.

Loss of apical growth is typical of phenoxy or hormonal herbicide injury. Affected trees may suffer a gradual crown dieback and eventually die. Lateral leaf development may also be hindered. Exposure to 2,4-D

Figure 14–1. Phenoxy herbicide injury to boxelder. Affected foliage is chlorotic, leaves are cupped, and chlorophyll in leaves appears variegated.



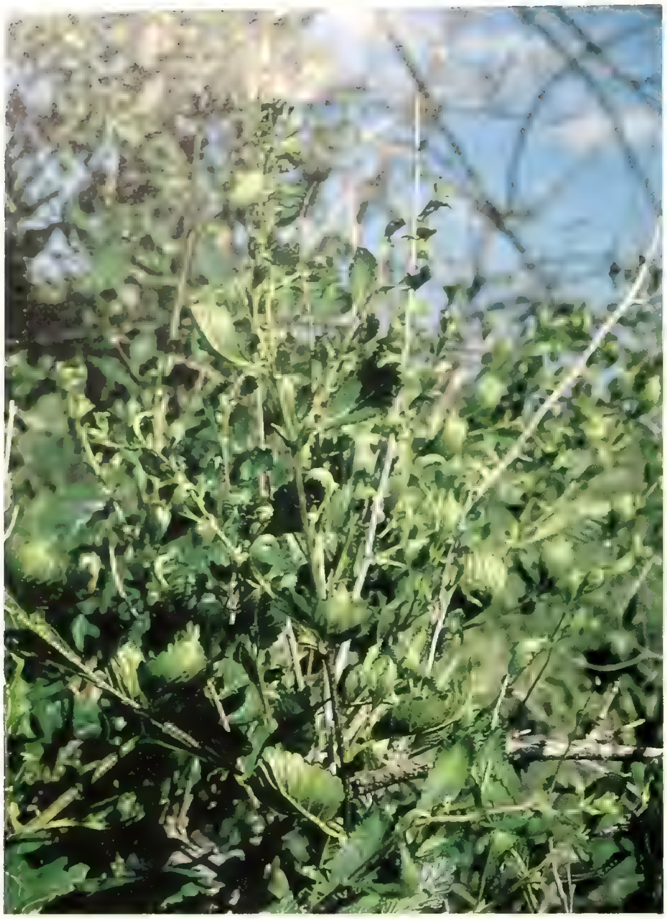


Figure 14-2. Foliage of Siberian elm becomes cupped when damaged by herbicides.

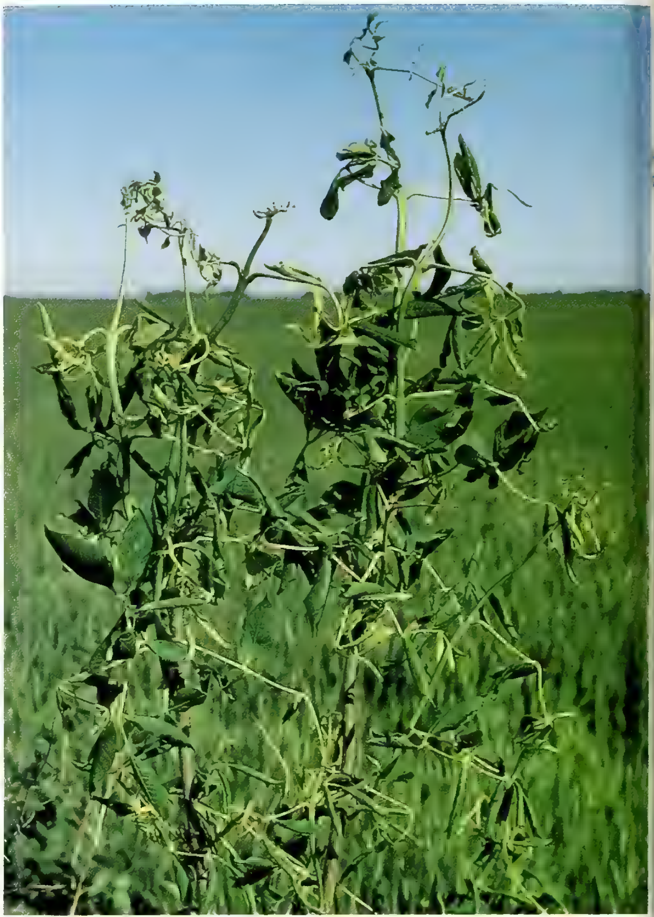


Figure 14-3. Green ash severely damaged by herbicides in a you windbreak. Note distortion of new growth and cupping of folia

may result in the production of fewer normal leaves, flowers, and fruits.

Leaf scorch can indicate herbicide injury, particularly when exposure is heavy. Ash and cottonwood may exhibit scorched leaves without expressing the more common effects of herbicide exposure.

Evergreens are generally resistant to phenoxy herbicides, but they may be injured under certain circumstances. Exposed fir trees may develop curled leader growth, burned needle tips, and needle cast. Spruce may also show terminal growth damage and needle cast (fig. 14–4). Pine trees are most susceptible to damage during periods of active growth, and candles exposed to phenoxy herbicide may develop nastic growth.

The non-hormonal type herbicides generally do not induce abnormal growth, but cause chlorosis and eventual death of affected tissue. With contact herbicides, such as paraquat, this damage is restricted to areas contacted.

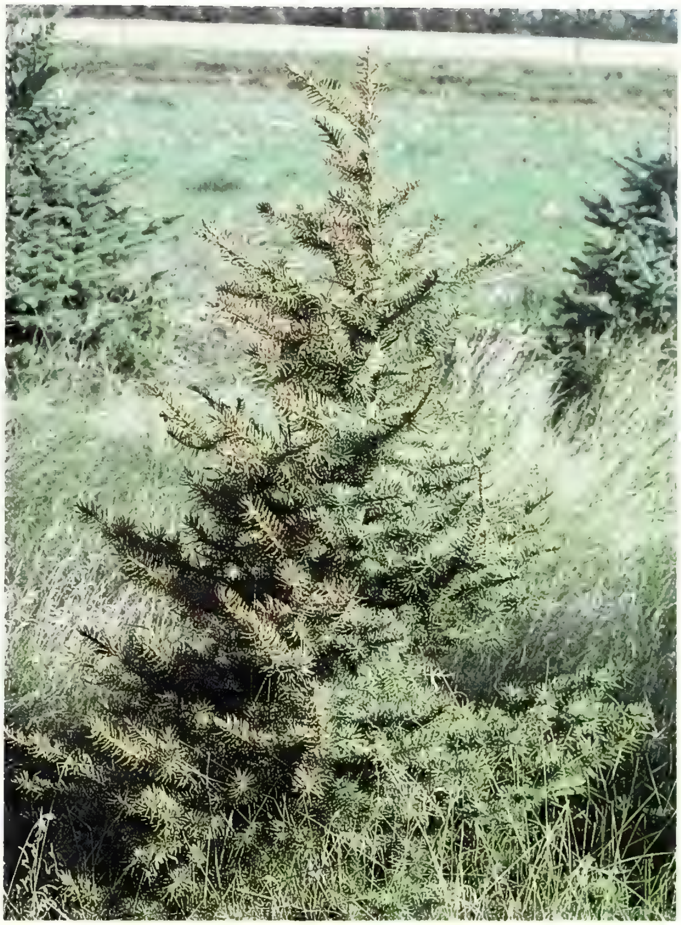
Diagnosis of herbicide damage can be aided by careful collection and analysis of residue samples. It is important that the samples be collected as soon as possible following exposure. It is necessary to specify the herbicides the laboratory should evaluate. With some herbicides, such as 2,4-D, it is necessary to specify the exact kind of 2,4-D. When possible, residue samples should b kept frozen until they reach the laboratory. It may be a-visable to contact an analysis laboratory for specific i-structions on collection and care of samples.

Damage

All possible sources of chemical exposure should b considered when dealing with suspected herbicid damage. Harmful exposure to herbicides can result fro drift of the spray particles, movement of volatiles, a-plication to the soil or movement in soil (or wat) resulting in root exposure, and direct application. Spr drift volatiles can move considerable distances, resultig in damage several miles from where the herbicide ws applied. Direct application may cause damage if sensitie desirable trees are not carefully avoided, or if selectie herbicides are misapplied directly over trees.

In urban areas, desirable plants are most likely to e damaged by lawn sprays or fertilizers that contain h-bicides. Damage is also commonly associated with sc-applied herbicides used around driveways, sidewal, and structures. In situations where damage has result from an apparent misuse of herbicides, it may be app-

ure 14-4. Colorado blue spruce with symptoms of MCPA her-
ide damage. Affected foliage is necrotic and some needles have
been cast prematurely.



iate to contact the state pesticide regulatory agency or
e U.S. Environmental Protection Agency.

ontrol

Desirable trees located where herbicide exposure is
kely will require protective effort. Persons who apply
erbicides should be informed of where desirable trees
e located, and products that pose a minimal risk to the
ees should be used. Extra caution should be exercised
ensure proper calibration and application. Once ex-
osure has occurred, little can be done to minimize the
itial effects. Washing herbicide off foliage can be ef-
ctive if it is done during or immediately after exposure.
oil-active herbicides can be deactivated on a limited
ale with activated charcoal or similar products.
enerally, any effort that promotes tree vigor should help
inimize the effects of the spray, except that regrowth
foliage should not be stimulated. Trees weakened by herbicides may be predisposed to insects, pathogens, and other types of environmental damage.

Selected References

Hibbs, R. H. Decline of hackberry attributed to ambient herbicide drift. Proceedings Iowa Academy of Science. 72(3–4): 187–190; 1976.

Hibbs, Robert H. Recognition of weed-killer injury to trees. Journal of Arboriculture. 4: 189–191; 1978.

Otta, J. D. Effects of 2,4-D herbicide on Siberian elm. Forest Science. 20: 287–290; 1974.

Phipps, Howard M. The role of 2,4-D in the appearance of a leaf blight of some plains tree species. Forest Science. 9: 283–288; 1963.

Sherwood, C. H.; Weigie, J. L.; Denisen, E. L. 2,4-D as an air pollutant; effects on growth of representative horticultural plants. Horticultural Science. 5: 202, 211–213; 1970.

15. Chlorosis

Mark O. Harrell and Mark W. Andrews

Many trees in the Great Plains suffer from nutrient deficiencies induced by alkaline soils. One symptom commonly produced by these deficiencies is a yellowing of the foliage, called chlorosis.

Hosts and Distribution

Chlorosis of foliage may develop wherever trees are grown in alkaline soils. Chlorosis generally is most severe in the western two-thirds of the Great Plains where highly alkaline soils are common. Chlorosis is also common in urban areas where excavation during construction of buildings brings alkaline subsoil to the surface.

Many tree species are susceptible to chlorosis. Pin oak and silver maple are commonly affected. Also susceptible are other oak and maple species, birches, cottonwood, poplars, elms, pines, junipers, yews, walnut, peach, and apple.

Symptoms and Signs

The degree of yellowing varies from a yellowish-green of leaves only slightly chlorotic to lemon-yellow and almost white in leaves severely chlorotic. In some cases the leaves have a slight reddish or "fall" coloration. The yellowing is most intense in the interveinal areas of leaves (fig. 15–1); brown, necrotic areas often develop in these areas on severely affected leaves, giving the appearance of leaf scorch.

Symptoms of chlorosis may be uniform throughout the entire tree or be confined to one or a few branches (fig. 15–2). Generally, leaves formed in early spring are normal in both color and size, but leaves formed later in the season become increasingly chlorotic and are smaller. If chlorosis continues for several years, shoot growth is reduced, branches begin to die back (fig. 15–3), and the tree eventually dies.

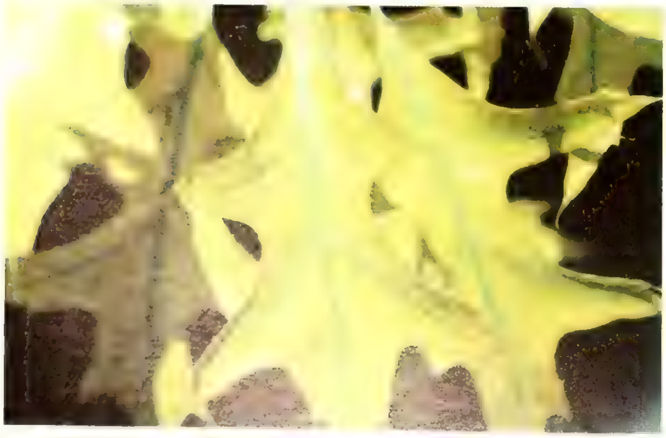


Figure 15-1. Chlorotic pin oak leaves showing typical green veins and ch[illegible]

Cause

Deficiency of iron is the most common cause of chlorosis of trees in the Great Plains. In most cases, iron in the soil is present in sufficient quantity; but under alkaline conditions (pH greater than 7.0), it is in an insoluble form. Reduced availability of nutrients occurs commonly in alkaline soils. Even if absorbed, these nutrients may remain in a form that the tree is unable to use. Iron is used in the production of chlorophyll, thus a deficiency of iron prevents the leaves from producing the normal amount of chlorophyll.

Deficiencies of other nutrients such as zinc, manganese, or nitrogen can contribute to chlorosis or in some cases they are the primary cause of chlorosis. Factors such as low temperature and high soil moisture, and excessive amounts of copper, manganese, zinc, and phosphorus can cause or contribute to development of chlorosis.

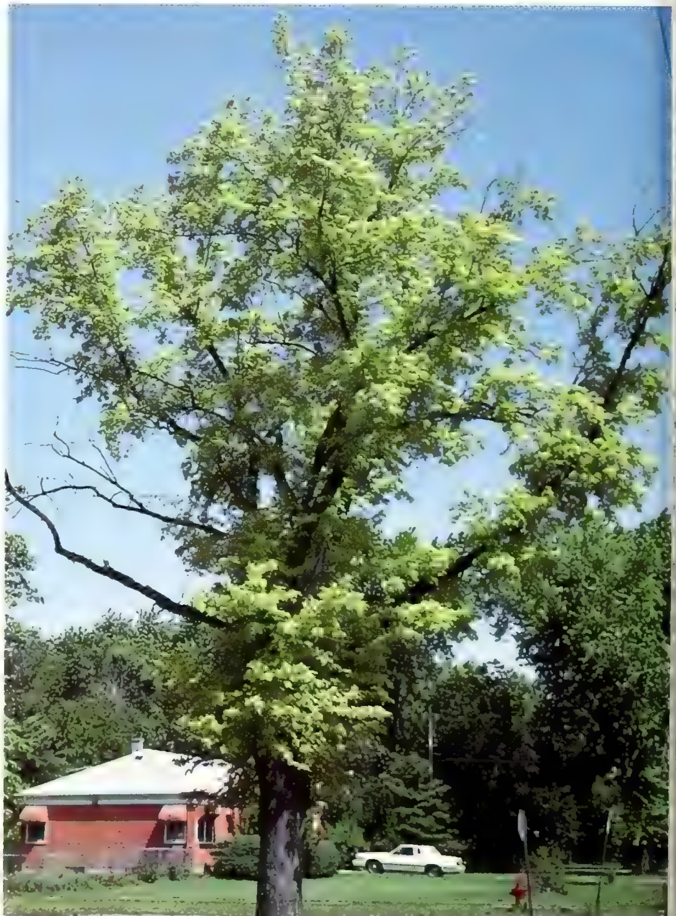
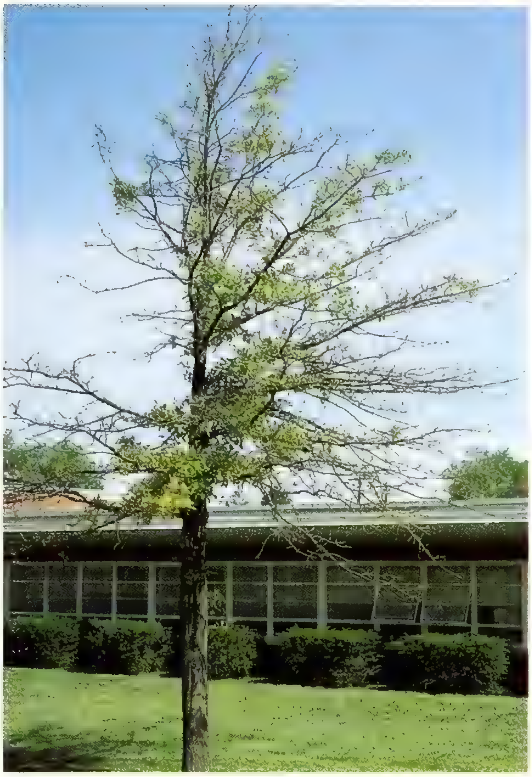
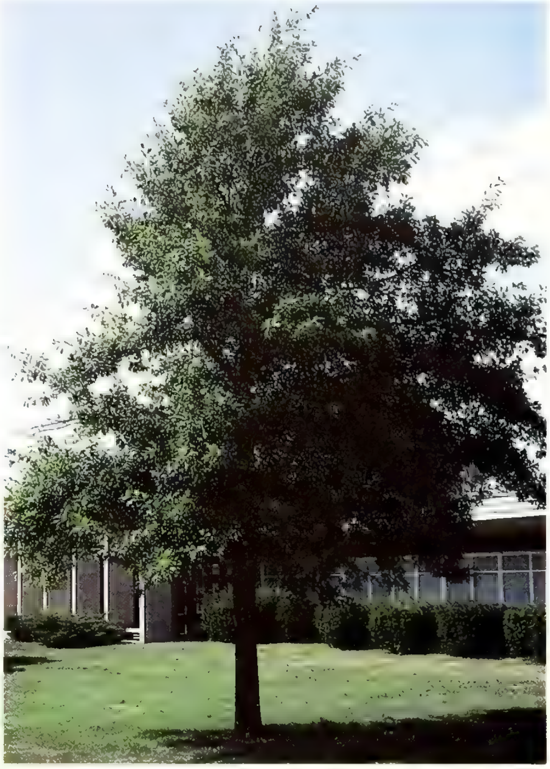


Figure 15-2. A moderately chlorotic silver maple with some bran dieback.

jure 15-3. A severely
lorotic pin oak with ex-
nsive branch dieback
ft).



gure 15-4. The same
e as in fig. 15-3 show-
g the improvement in
af color and crown full-
ss 2 years after a trunk
jection with ferrous
sulfate (right).



amage

Homeowners with chlorotic trees commonly spend
20 to $50 per tree every 3 or 4 years for therapeutic
eatments. Without treatment, the trees would continue
decline and die. In many areas of the Great Plains
ome species, especially pin oak, are no longer being
lanted because this disorder severely reduces their
hance of survival.

ontrol

Three methods can be used to treat chlorosis caused
y iron deficiency: (1) spraying the foliage with a solu-
on of ferrous sulfate (iron sulfate) or chelated iron; (2)
corporating ferrous sulfate and sulfur, or chelated iron
to the soil; and (3) injecting ferrous sulfate or chelated
on into tree trunks.

Spray treatment gives the quickest response, but is the
ost temporary. This treatment only improves the con-
ition of leaves present when foliage is sprayed. It has
ttle or no effect on leaves formed after spraying, and
e effectiveness does not carry over into the next grow-
g season. This treatment is not recommended for long-
rm control of chlorosis. It is only used on trees when
hlorosis is extremely severe and a quick response is
esired.

Soil treatment provides the most permanent control
f chlorosis. A single soil treatment is often effective for
to 5 years. The disadvantages of this treatment are that
may not become effective until the next growing
eason, and it requires considerable labor and materials. This treatment is often recommended for shrubs and trees that are too small for trunk injections, and in cases where the landowner wants to avoid making the wounds required for trunk injections. The recommended materials and rates are: (1) 2 to 2.5 pounds per inch tree diameter of a mixture of equal parts ferrous sulfate and sulfur, or (2) an iron chelate used at the rate indicated on the label. Several chelated iron materials are available.

Trunk injection is the most commonly used treatment for chlorosis. This treatment involves drilling holes into the lower trunk and either placing capsules of powdered material into the holes, or injecting a liquid solution through the holes. Trees usually respond within 3 to 4 weeks, and the treatment is generally effective for 2 to 4 years (fig. 15–4). More information on procedures and materials is available from most nurseries and garden stores. Some materials can be applied easily by the homeowner, while others are applied only by trained arborists. Follow label recommendations for application rates.

Selected References

Harrell, M. O.; Pierce, P. A.; Mooter, D. P.; Webster, B. L. A comparison of treatments for chlorosis of pin oak and silver maple. Journal of Arboriculture. 10: 246–249; 1984.

Neely, Dan. Iron deficiency chlorosis of shade trees. Journal of Arboriculture. 2: 128–130; 1976.

Neely, Dan. Trunk and soil chlorosis treatments of pin oak. Journal of Arboriculture. 6: 298–299; 1980.

16. Botryodiplodia Canker of Elms

Jerry W. Riffle and Joseph M. Krupinsky

Botryodiplodia canker of elms is caused by the fungus *Botryodiplodia hypodermia.*

Hosts and Distribution

Botryodiplodia canker has been found on American, Siberian, English, and smooth-leaved elms in the United States; it occurs principally on Siberian elm in North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Minnesota, and Montana. In 1979, *B. hypodermia* was recovered from 256 of 609 Siberian elm cankers collected in 56 counties in four States in the northern Great Plains.

Symptoms and Signs

The surface of Siberian elm bark infected with *B. hypodermia* becomes reddish-brown to black, and frequently splits longitudinally (fig. 16–1). The outer bark may become loose and coil back upon itself. Infected inner bark tissues turn reddish-brown to brownish-black, and become water-soaked and very soft. The cambium and sapwood immediately beneath infected bark becomes red brown; this discoloration ends at th margins of the canker (fig. 16–2). When the fungu girdles an infected stem, the cambium is killed, th foliage wilts, and stem tissue distal to the canker dies Adventitious sprouts often develop below girdlin cankers, giving infected trees a bushy appearance.

Yellow foliar symptoms on American elm, whic superficially resemble those of Dutch elm disease, ma be caused by *B. hypodermia.*

The fungus produces numerous globose to flask shaped fruiting bodies (pycnidia) on patches of dying an dead bark near canker margins (fig. 16–1). They appea as small, black, pimple-like eruptions in bark tissue (fig. 16–3). Both one-celled hyaline conidia and tw celled brown conidia may develop in pycnidia. Nearl all *B. hypodermia* conidia from cankers in the Grea Plains are one-celled, hyaline, and measure 20–32 b 15–18 μm (fig. 16–4).

Disease Cycle

Growth and spore production by *B. hypodermia* are op

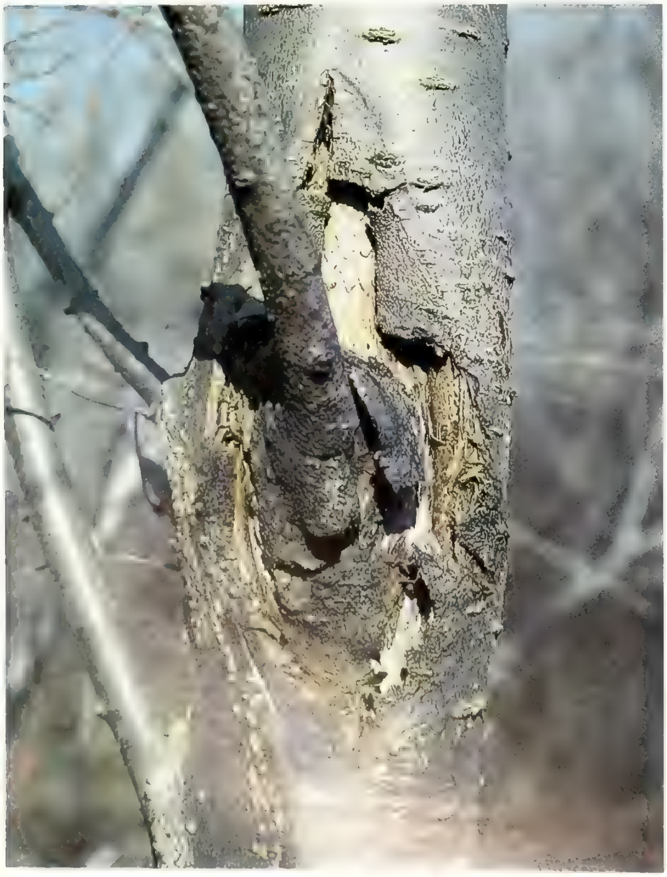
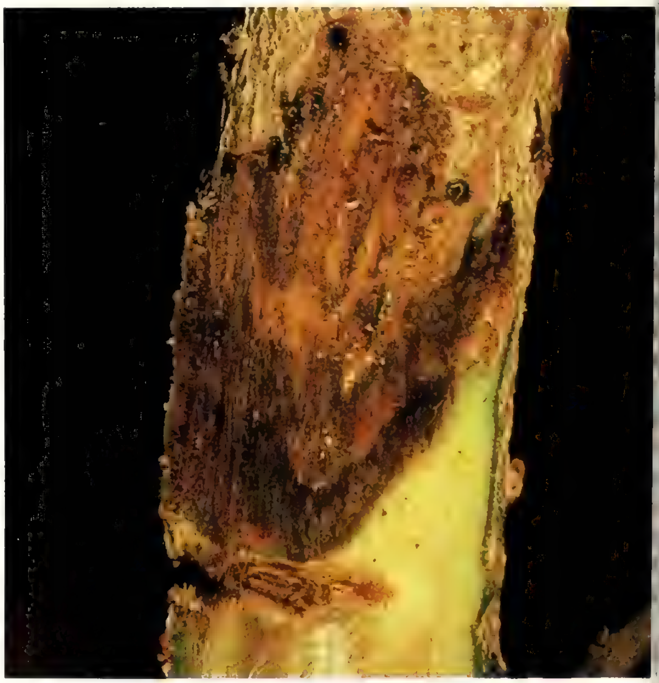


Figure 16-1. Natural canker originating at dead branch on windbrea tree.

Figure 16-2. Red-brown discoloration of inner bark and sapwo at junction of infected and healthy (nondiscolored) stem tissu of Siberian elm.



um at 77° F in vitro on potato dextrose agar. Con- a are exuded from pycnidia after rains and are bably dispersed in water droplets or by wind. unded bark is infected readily during the growing son of the host. Infections of wounded Siberian elm k in early spring, late fall, and winter months usual- produce small cankers that are callused over during next growing season. Girdling cankers develop rapid- luring dry summer months when demand for water high and temperatures range from 61° to 86°F. Pyc- lia develop predominantly in the fall in dead or dy- bark. The fungus overwinters as fruiting bodies or celium in cankered bark.

'actors contributing to stress, including drought and nter injury, appear to increase susceptibility of elms nfection by *B. hypodermia*. Some herbicides, such as -D, alter the normal development of bark tissues in erian elm and may increase its susceptibility to ection.

/irulence of isolates of *B. hypodermia* varies. Typical lates, which have dark gray to black mycelium in ture, cause greater disease development on Siberian than do atypical isolates. Atypical isolates have gray white mycelium in culture and their cirrhi are white d contain aseptate hyaline spores when first extruded m pycnidia.

mage

3. *hypodermia* is the most damaging canker pathogen Siberian elm in the Great Plains. It causes dieback and ath of infected trees, and has severely limited the efulness of this species in windbreaks. Because infec- n in windbreaks frequently occurs on large branches d boles of trees, major branches and entire trees are dled and killed. Damage is most severe during dry mmer months in the central Plains. In a seasonal in- ulation study in south central Nebraska, 44 of 48 trees oculated during the period July through September bsequently died or had extensive branch dieback.

ntrol

Control of canker diseases involves both disease pre- ntion and treatment of the disease. Disease prevention volves growing vigorous trees to prevent entrance of thogens into the bark. Wounds are essential for the ablishment of *B. hypodermia* infections. Thus, the best eventive measure is to avoid wounds, especially in the mediate area of active cankers containing fungus ores.

New plantings should be established on good sites with gorous planting stock, and weeds should be controlled r several years after planting. Improve vigor of land- ape trees by deep watering, especially during dry sum- er months, and maintain good drainage. Sunscald on wly planted trees may be prevented by wrapping the les with burlap, kraft paper, or special tree-wrapping per.

Genetic variation in resistance to *B. hypodermia* has en observed in Siberian elm nursery stock. This genetic resistance is being incorporated into a tree improvement program in North Dakota, and will be available in future cultivars of Siberian elm.

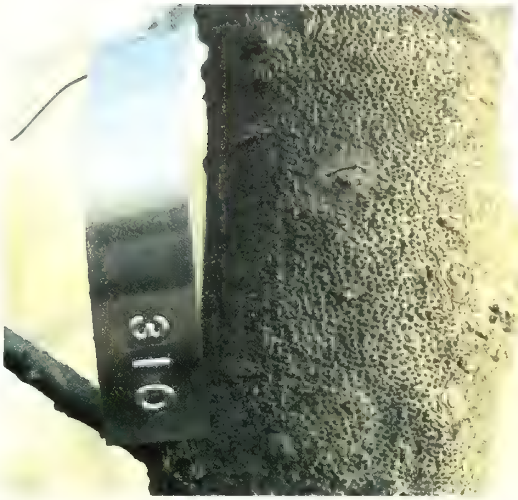
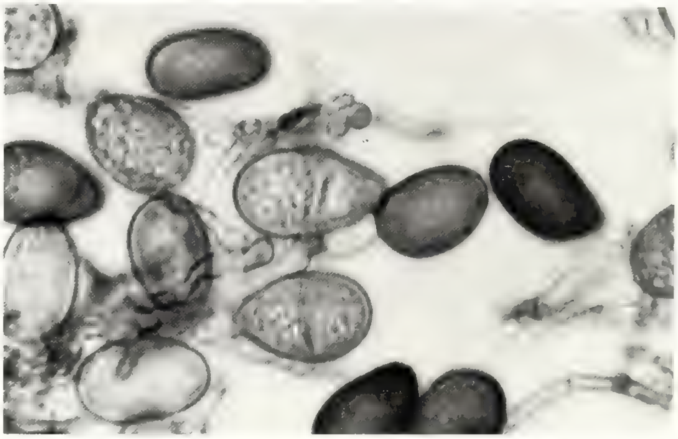


Figure 16-3. Extensive pycnidia development on dead bark of Siberian elm sapling 44 days after inoculation with *B. hypodermia*.

Figure 16-4. One-celled conidia, 200X.



Treatment of the disease involves pruning dead, dying, or severely cankered branches from infected trees during winter or before spring rains to prevent fungal spores from splashing to new infection sites. Severely infected or dead cankered trees should be removed and destroyed, because they may otherwise serve as a reservoir of spores for several years.

Selected References

Krupinsky, J. M. *Botryodiplodia hypodermia* and *Tubercularia ulmea* in cankers on Siberian elm in northern Great Plain windbreaks. Plant Disease. 65: 677–678; 1981.

Riffle, Jerry W. Cankers. In: Stipes, R. Jay; Campana, Richard J. eds. Compendium of elm diseases. American Phytopathological Society; St. Paul, MN: 1981: 34–42.

17. Tubercularia Canker of Siberian Elm and Russian-Olive

Joseph M. Krupinsky and James A. Walla

Tubercularia ulmea causes Tubercularia canker on Siberian elm and Russian-olive.

Hosts and Distribution

Tubercularia canker is widely distributed on Siberian elm and Russian-olive in the northern Great Plains. In 1979, *T. ulmea* was isolated from 17 percent of 609 Siberian elm cankers collected in 56 counties in Minnesota, Montana, North Dakota, and South Dakota. It has been reported on both hosts in the Canadian Prairie Provinces.

Tubercularia has a wide host range. During 1971 through 1975 *T. ulmea* was identified (confirmed by J. C. Carter) on 28 different host plants in North Dakota. *T. vulgaris*, the asexual stage of *Nectria cinnabarina*, is similar to *T. ulmea* and occurs on honeylocust and other hardwoods in the Great Plains.

Symptoms and Signs

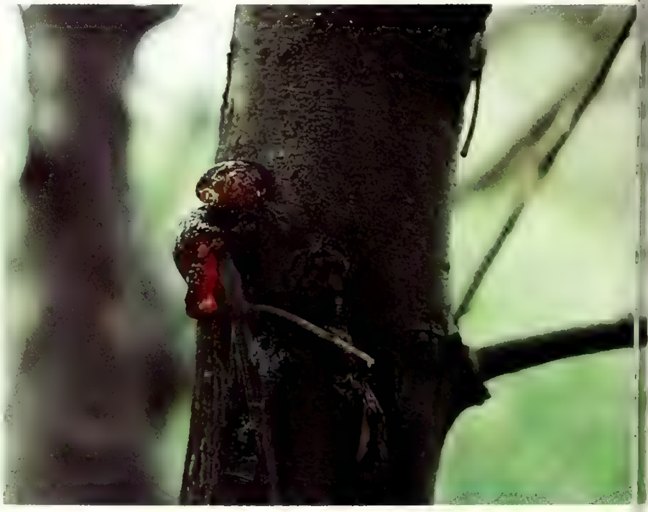
Oval to elongate Tubercularia cankers can develop on trunks, branches, and twigs of affected trees. Flags, recently killed branches with dead leaves still attached, can indicate the presence of a canker that has girdle the stem (fig. 17–1). Gum deposits may be found o Russian-olive branches and stems attacked by *Tube* *cularia* (fig. 17–2).

The surface of infected bark is red-brown, and becom brown to black as it dies and dries out. Sporodoch (fungal fruiting bodies) initially are produced in th diseased bark and emerge onto the bark surface. Ir mature sporodochia range from tan to orange to bla (fig. 17–3); sporodochia become black as they matu (fig. 17–4). Sporodochia, which can be scattered gregarious, may be up to 1.5 mm in diameter and up 0.9 mm high. Conidiophores are hyaline, straight strongly curved, and mostly 45–65 by 1.5–2.5 μm. Spor (conidia) from sporodochia are one-celled, hyaline, ovo to oblong, and usually 4.6–6.2 by 1.5–2.3 μm (fig. 17–

T. ulmea readily colonizes dead or broken branche thus the presence of its sporodochia on a dead bran does not necessarily mean that it killed the branc Sporodochia may not be present on young cankers. this stage, wood chips from the edge of the canker mu be cultured on agar to confirm the presence of *T. ulme* Other canker-causing organisms, such as *Botryodiploc* *hypodermia* on Siberian elm and *B. theobromae* a *Phomopsis arnoldiae* (syn. *P. elaeagni*) on Russian-oli can cause similar cankers and may be present. The co idial stage of *Nectria cinnabarina (Tubercularia vulgar* is similar to *T. ulmea*.

Figure 17-1. Flagging of Russian-olive stems caused by Tub cularia canker.

Figure 17-2. Gum deposits may develop on Russian-olive bran infected by *T. ulmea*.



sease Cycle

onidia liberated from sporodochia on cankers and on
ad branches spread to and infect dead trees, or living
es that have been wounded. *Tubercularia* is a wound
thogen, and only infects living trees through wounds
the bark, such as those caused by hail, wind, snow,
tle, cultivation, or herbicide damage. The fungus can
found on weakened twigs and branches in the shaded
erior of tree crowns. It is considered a weak parasite,
d often infects stressed trees. Infections of wounded
rk can either result in small cankers that callus over
ring the next season or in girdling cankers. The fungus
casionally causes perennial cankers. It overwinters as
iting bodies and mycelium in cankered bark.

mage

Tubercularia causes dieback or death of infected trees.
ubercularia canker appears to be a more important
sease on Russian-olive than on Siberian elm. *T. ulmea*
s isolated more frequently from girdling cankers on
ussian-olive collected in North and South Dakota than
her *B. theobromae* or *P. arnoldiae* (Krupinsky, unpub-
hed). Although *T. ulmea* was isolated from girdling
nkers on Siberian elm, it was considered secondary
importance to *B. hypodermia*, which was considered
e primary pathogen.

ntrol

Because healthy trees are less susceptible to infection
d damage, trees should be managed for optimum
gor. If possible, water and fertilize trees as needed.
ew plantings should be on good sites with vigorous
anting stock and good weed control. Reduce chances
infection by preventing wounds, and do not bring in-
cted material into uninfected areas. Because severely
fected or dead branches are a source of fungal spores,
ey should be removed and destroyed. Prune back to
e nearest living branch beyond the canker. Prune dur-
g dry weather. Disinfect pruning tools with alcohol
ter each cut, and apply fungicidal wound dressing to
cuts. Protective fungicides are registered for control
wound fungi on trees, but none are specifically labeled
r this fungus. Genetic variation in disease resistance
s been observed in common Siberian elm nursery
ock. This genetic resistance is being utilized in a tree
provement program, and will be available in future
ltivars of Siberian elm.

lected References

arter, J. C. Tubercularia canker and dieback of Siberian elm (*Ulmus pumila* L.). Phytopathology. 37: 243–246; 1947.

rupinsky, J. M. *Botryodiplodia hypodermia* and *Tubercularia ulmea* in cankers on Siberian elm in northern Great Plains windbreaks. Plant Disease. 65: 677–678; 1981.

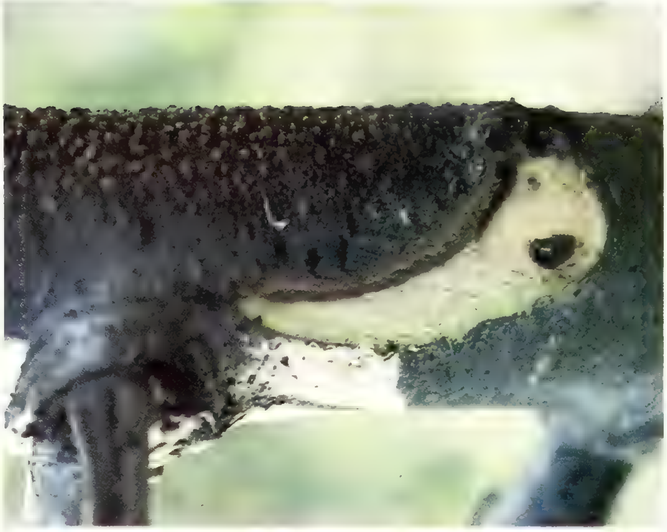
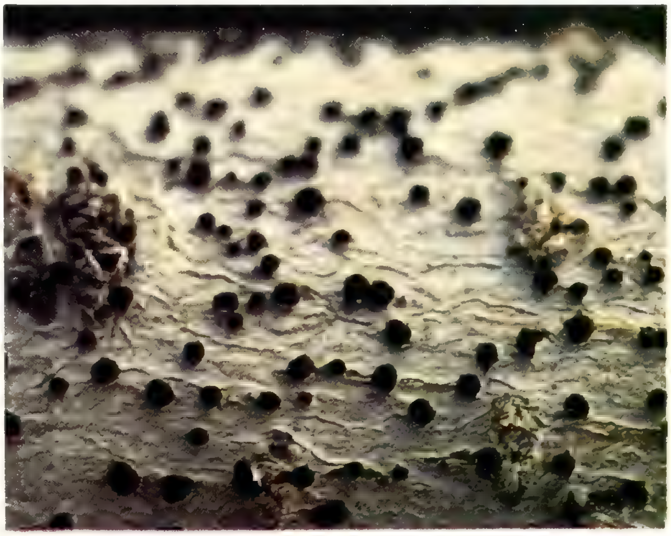


Figure 17-3. Immature sporodochia on surface of canker on Russian-olive. Removal of bark reveals canker margin.

Figure 17-4. Mature black sporodochia on bark of Siberian elm.



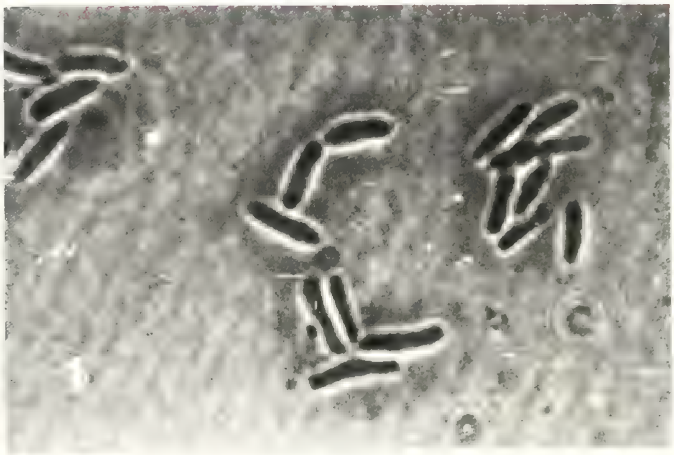


Figure 17-5. Conidia of *T. ulmea* from sporodochia.

18. Botryodiplodia Disease of Russian-Olive

Glenn W. Peterson and Harrison L. Morton

Russian-olive has been planted in the Great Plains for over 65 years. Early reports indicated that Russian-olive was highly adapted to Plains conditions, and was free of serious diseases and insect pests. Thus, this species was used extensively in windbreaks established in the Great Plains by the Prairie States Forestry Project (1935–1942). An investigation in the 1960's however, revealed that the fungus *Botryodiplodia theobromae* was causing a serious stem disease of Russian-olive in windbreaks in Nebraska (fig. 18–1).

Hosts and Distribution

B. theobromae has a wide host range that includes association with cankers of sycamore (see Article 20) and live oak, and with stained wood in the southern United States. The fungus has been found on Russian-olive in Nebraska and Oklahoma. Because autumn olive is being planted at an increasing rate in the Great Plains, inoculations were made to determine whether this related species is also damaged by *B. theobromae.* Inoculated seedlings exuded some gum and the fungus was recovered 6 weeks after inoculation, but no damage was evident after 5 months.

Symptoms and Signs

Typically, bark and cambium tissues are killed in strip extending many feet along stems and branches. Callu tissue usually does not form at the margin of the dea strips. Although the dead strips are not readily apparen on the bark surface, their presence on stems and majo branches is often indicated by small dead branches alon the strips. These small branches die as their base become engulfed by necrotic tissue. Mortality of sma branches can be detected most readily in the uppe crown during July and August. Major branches may hav more than one strip of dead tissue. The strips sometime spiral along stems.

Infected trees sometimes exude gum from stems an branches (fig. 18–2), but gum is not a reliable indicato of this disease. Other pathogens can also cause gummin Copious exudation may occur at the base of stems, b gum also can be found on branches of all sizes includin current-year growth.

Disease Cycle

Information on the disease cycle is limited. The sour of infection of Russian-olive in field plantings is n

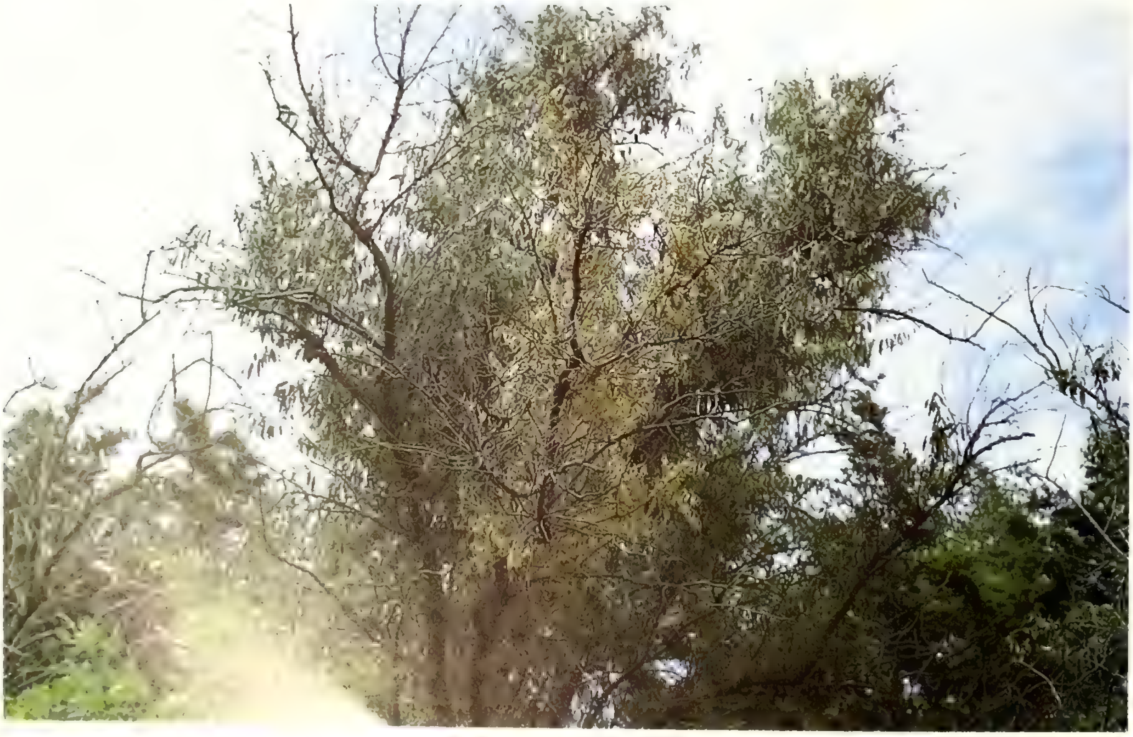
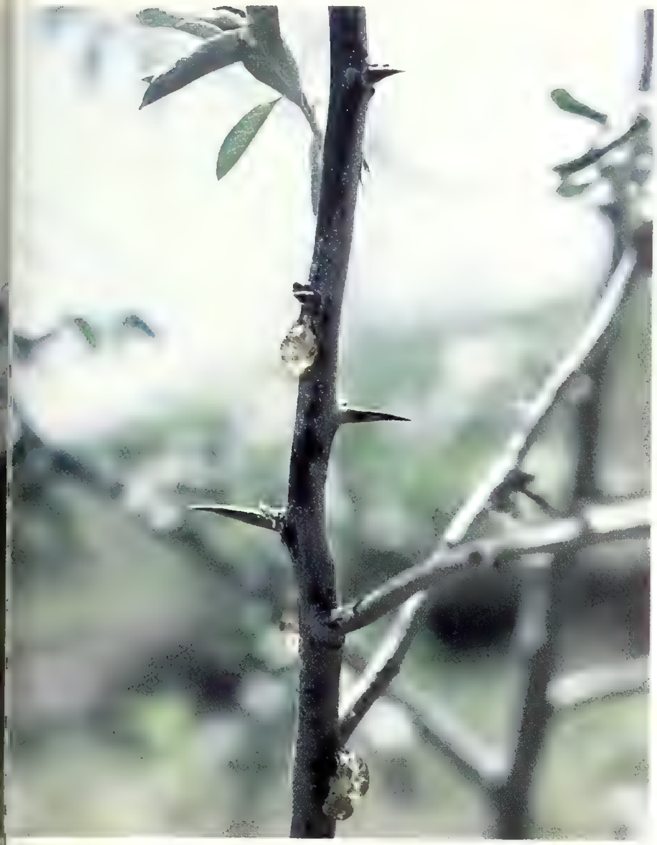


Figure 18-1. Russia olive infected by *Botryodiplodia theobromae*.



jure 18-2. Gum on trunk of Russian-olive infected by *B. theobromae.*

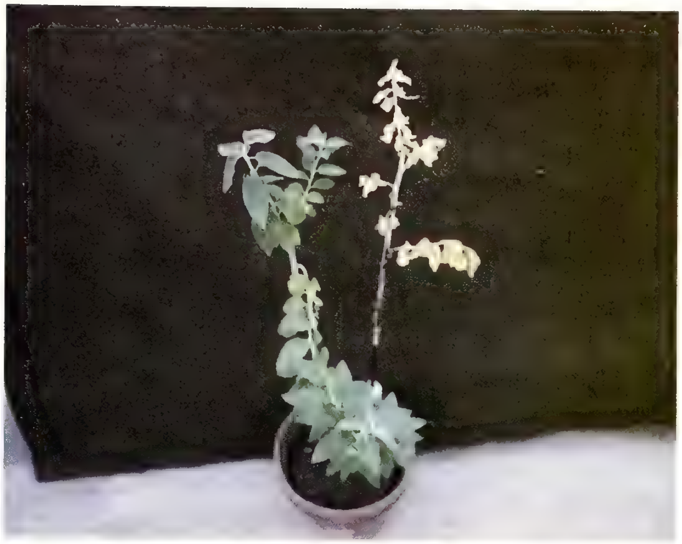
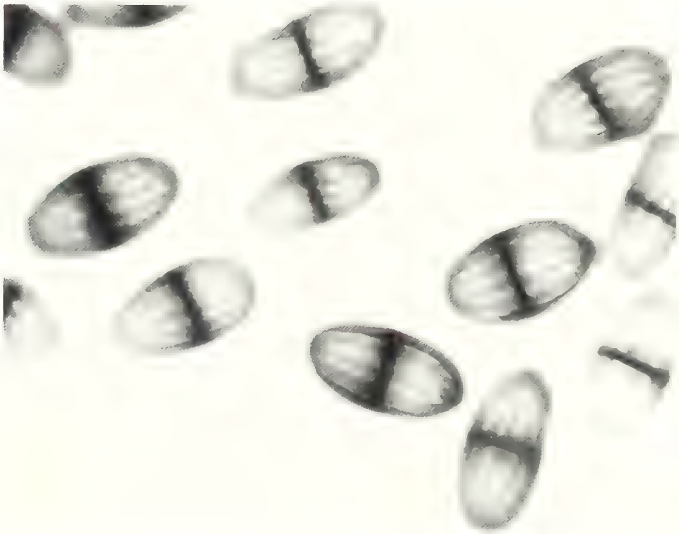


Figure 18-3. Russian-olive seedling inoculated with *B. theobromae.*

Figure 18-4. Spores of *B. theobromae* (800X).



own; the fungus has not been detected on seedlings nurseries (fig.18–3). Because *B. theobromae* has such wide host range there may be other tree species in or jacent to Russian-olive plantings that are a source of ores for new infections. Infection likely follows ounding of trees. Pycnidia are formed on the bark of ad branches. Spores produced in these pycnidia are ipsoid to obovoid, walls are thick, striated, and not nstricted at the septum; the spore surface is smooth g. 18–4). The average size of spores from Russian-olive 16.4 by 30.4 μm. Spores are usually hyaline and nseptate when extruded from pycnidia, becoming rk brown and septate after extrusion. The fungus has gh temperature optima for growth (86°F), and germ be development (93°F).

amage

Tissues are killed rapidly in a longitudinal direction, t slowly in a transverse direction. Complete girdling main stems may take many years. Infected trees may ve some dead stems, other stems with many small anches dead and dying, and others with no appreciable mage. Vigorous sprouts developed from stumps after fected 20-year-old Russian-olive trees were cut; however, within 2 years many of these sprouts were extenvely cankered, and within 4 years most were dead.

In a 1960 survey of 44 windbreaks established during e period 1935–1942 in 14 eastern Nebraska counties, me 30 percent of the Russian-olive were dead or nearly so. *B. theobromae* frequently was isolated from dying and recently killed branches.

Control

The lack of information on the disease cycle limits the recommendations that can be made to reduce the impact of this disease. The 1960 survey in Nebraska did not give any indication of factors that might decrease the threat of this disease. Surveillance will be required to determine whether there are areas in the Great Plains where this disease is not a threat.

Selected References

Lewis, R. Jr.; Van Arsdel, E. P. Vulnerability of water-stressed sycamores to strains of *Botryodiplodia theobromae.* Plant Disease Reporter. 62: 62–63; 1978.

Peterson, Glenn W. Disease of Russian-olive caused by *Botryodiplodia theobromae.* Plant Disease Reporter. 60: 490–494; 1976.

19. Phomopsis Canker of Russian-Olive

Harrison L. Morton and Joseph M. Krupinsky

Russian-olive is used in windbreaks and in landscape plantings. It has been planted widely in windbreaks in the northern Great Plains because it survives rigorous environmental conditions. It is particularly tolerant of soil salt and drought. Unfortunately, it is susceptible to several fungal canker diseases: Phomopsis canker caused by *Phomopsis arnoldiae* (syn. *P. elaeagni*); Botryodiplodia canker caused by *Botryodiplodia theobromae*; and Tubercularia canker caused by *Tubercularia ulmea*. Information on Botryodiplodia and Tubercularia cankers is included elsewhere in this Handbook.

Hosts and Distribution

P. arnoldiae is one of the three pathogens causing cankers on Russian-olive in the northern Great Plains (Krupinsky, unpublished). Phomopsis canker appears to be the most important canker disease of Russian-olive throughout the North Central and Northeast United States. The disease was first found in Missouri in 196 and subsequently in Illinois, Ohio, Delaware, Michiga and New York. The only other recorded host is blac walnut nursery seedling stock in Indiana.

Symptoms and Signs

Recently killed branches with dead leaves still attache (flags) indicate the presence of a canker that has girdle the stem (fig. 19–1). The primary symptom is an elo gated reddish-brown to purplish-black canker (fig. 19– There is often an obvious canker margin in bark tissu especially in older tissue. The sapwood immediate beneath the bark canker is brown, and this browni may extend beyond the margin of the canker.

Cankers often develop on shoots of the current yea Young shoots are girdled quickly, wilting the new silve foliage. Phomopsis cankers also have been found branches up to 4 inches in diameter. Frequently the

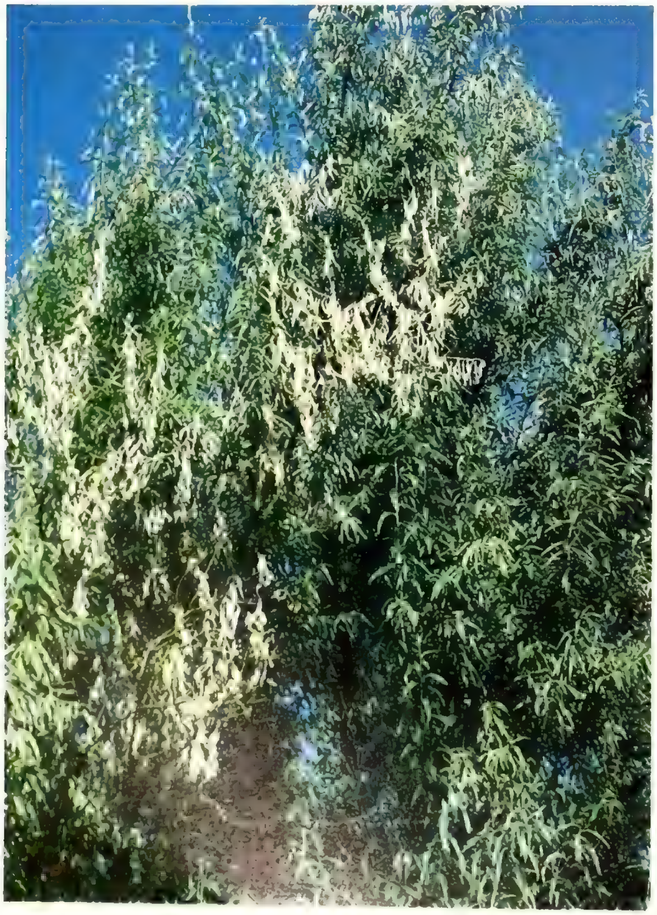


Figure 19-1. Flagged branches with attached, wilted foliage.

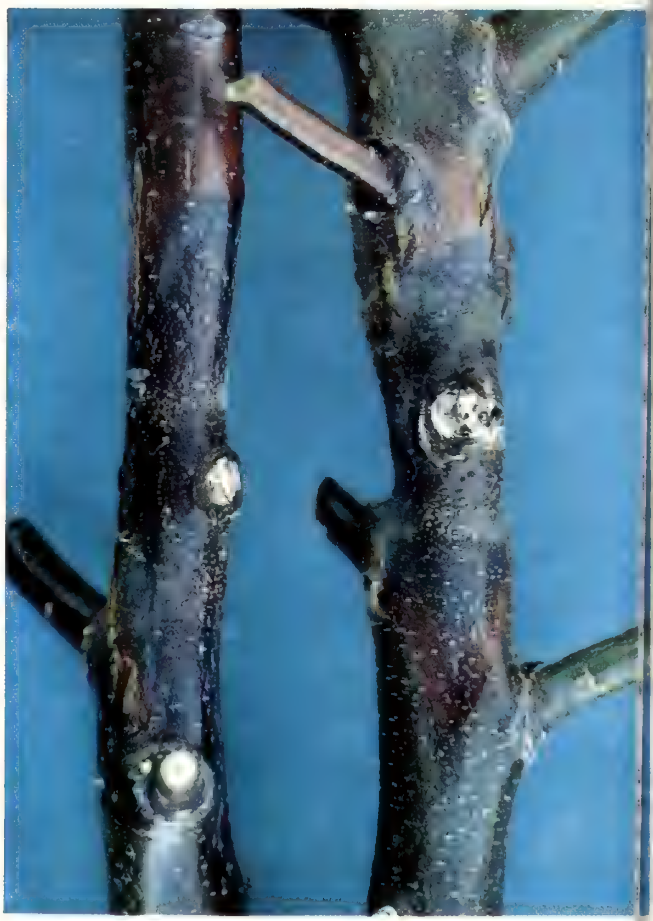


Figure 19-2. Elongated canker with reddish brown to purplish-b ck bark.

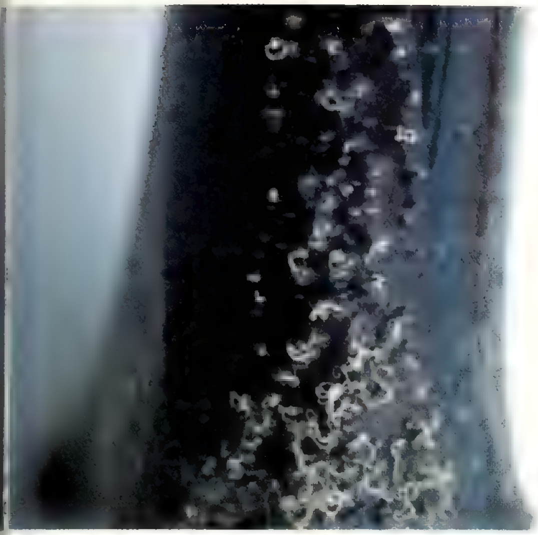


Figure 19-3. Conidia exuding from pycnidia of dying bark.

Figure 19-4. Alpha (shorter) and beta (longer) conidia of *Phomopsis arnoldiae.*

gum deposits around the margins of cankers.
Artificial inoculation sometimes produced pycnidia in
rk tissues within days; they are usually produced the
me season. The pycnidia are multiloculate, usually
egarious on affected bark, erumpent, and 275 µm
ameter by 500 µm high. Conidia exuded from pycnidia
g. 19–3) are of two types. Alpha conidia are short
-11 µm long), blunt, and straight; beta conidia are long
–26 µm), filiform, and curved (fig. 19–4). Both spore
pes are produced on plant tissue and sometimes in
lture.

When fruiting bodies are not present, the pathogen is
nfirmed by incubating wood chips, taken from the
ge of the canker, on a nutrient medium until the fungus
oduces white fluffy aerial hyphae and pycnidia in
oma. *B. theobromae* and *T. ulmea* can cause similar
nkers and may be present, particularly in the northern
eat Plains.

sease Cycle

The life cycle of the parasite has not been demon-
ated, but observations of naturally infected trees sug-
st that most infection occurs on new growth. It is not
own whether natural infection takes place throughout
e growing season. Cankers develop within a few days
llowing natural infection or artificial inoculation.
orulation on infected tissue also follows quickly.

amage

Infected Russian-olive and black walnut nursery stock
ust be culled and regraded. Terminal dieback of black
alnut leads to multiple-stemmed trees. In the North
entral States esthetic damage to ornamentals is most
rious. While young ornamentals may appear to be
sease-free, an inspection of trees in southeastern Mich-
an indicated that 52 percent of Russian-olive was in-
cted. Both disease incidence and severity increase with
e until plant appearance is no longer acceptable. In
the northern Great Plains, the disease contributes to the decline of Russian-olive windbreaks.

Control

Because healthy trees are less susceptible to infection and damage, trees should be managed for optimum vigor. If possible, water and fertilize trees as needed. Establish new plantings on good sites with vigorous planting stock, and control weeds. Reduce chances of infection by preventing wounds to the bark. Do not bring infected material into nondiseased areas. Because severely infected or dead branches of trees are a source of fungal inoculum, the branches should be removed from the site and burned. Infected branches should be pruned back to the nearest living branch beyond the canker. On specimen trees, the fungus was found no more than 6 inches below the canker margin. Trees should be pruned during dry weather, and pruning tools should be disinfected with alcohol after each cut. Preliminary results suggest that new canker development may be inhibited by systemic chemicals. Another option may be the use of resistant varieties. The newly released Russian-olive variety 'King Red' is described as being disease resistant.

Selected References

Carter, J. C.; Sacamano, Charles M. Fusicoccum canker, a new disease of Russian olive. Mycologia. 59: 535–537; 1967.

Maffei, H. M.; Morton, H. L. Phomopsis canker of Russian-olive in southeastern Michigan. Plant Disease. 67: 964–965; 1983.

Morehart, A. L.; Carroll, R. B.; Stuart, M. Phomopsis canker and dieback of *Elaeagnus angustifolia.* Plant Disease. 64: 66–69; 1980.

Stewart, J.; Worf, G. Fungicide control of Phomopsis canker of Russian olive. American Phytopathological Society; Fungicide and nematicide tests. 38: 185; 1983.

20. Botryodiplodia Canker of Sycamore

Robert Lewis, Jr., and Kenneth E. Conway

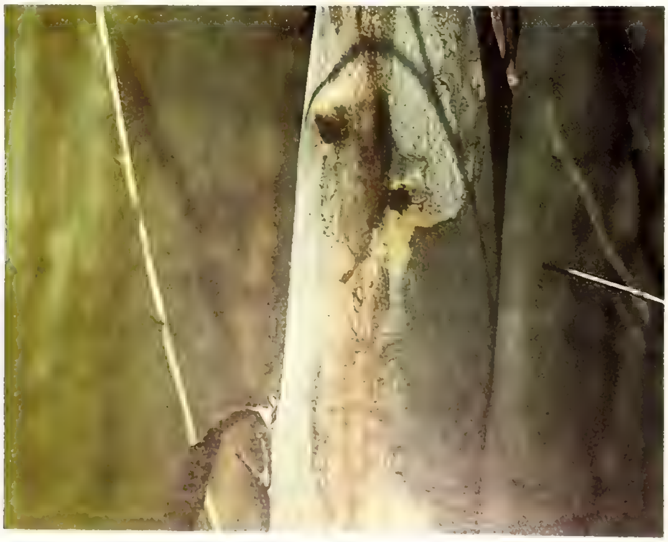
American sycamore is native to the eastern half of the United States, including some eastern parts of the Great Plains. It is planted frequently in rural and urban environments for noncommercial uses, but is also grown in plantations for economic return in hardwood-related industries. American sycamore grows best on moist sites, but will thrive on a variety of soil and moisture conditions. Natural stands are most common along lakes, rivers, and streams. The dry climate of the Great Plains is a limiting factor for American sycamore. When planted on dry sites, sycamore becomes more vulnerable to cankers caused by *Botryodiplodia theobromae*.

Hosts and Distribution

B. theobromae has a broad host range and geographical distribution. There are at least 48 synonyms for this fungus. Among the names most commonly used in recent years are *Diplodia theobromae, D. natalensis*, and *Lasiodiplodia theobromae*. The perfect stage of the fungus is known by the name *Botryosphaeria rhodina*.

B. theobromae is found throughout the world on a large variety of plants in tropical, subtropical, and temperate zones. It causes cankers in trees located in temperate zones. Its hosts in or near the Great Plains are Ailanthus, hickory, flowering dogwood, persimmon, American holly, walnut, and oak. The fungus is only weakly pathogenic in some of these trees, and may cause cankers only when trees are severely stressed.

Figure 20-1. Incipient *Botryodiplodia theobromae* canker of sycamore.



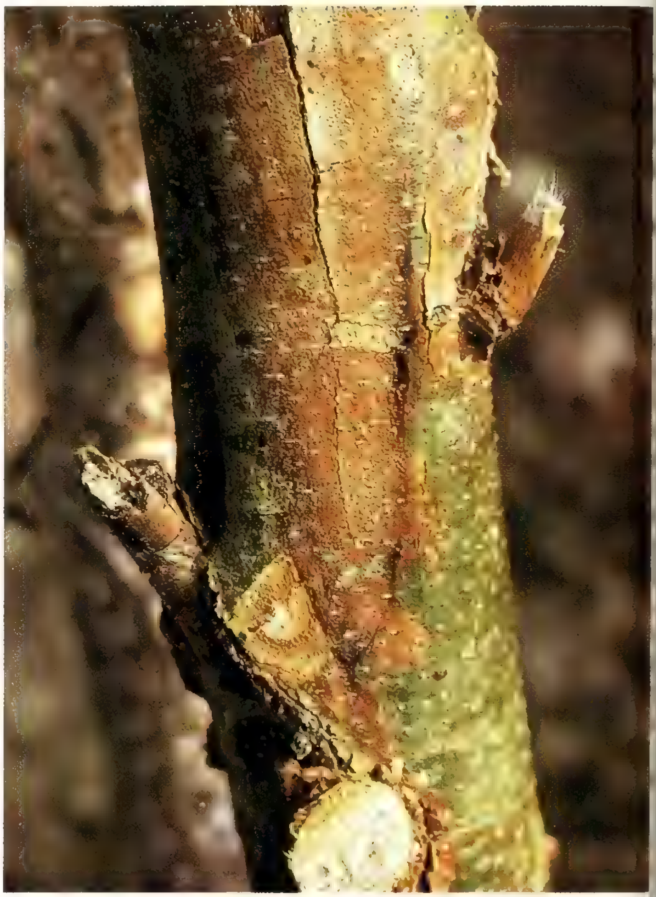


Figure 20-2. Advancing edge of large canker.

Symptoms and Signs

Botrydiplodia cankers in sycamore develop on bo limbs and boles. The cankers are inconspicuous duri initial development and detectable only by careful e amination. Incipient cankers have tan to dark brov streaks in the normally green to white, smooth bark sycamore (fig. 20–1). The streaks usually run longit dinally with the grain of the wood. As cankers enlar and age, cracks appear in the affected bark, and call forms around dead tissue (fig. 20–2). Old, inacti cankers appear flattened, sunken, and completely su rounded by callus (fig. 20–3). Cankers vary from a fe cm to several m in length.

B. theobromae also causes twig and limb dieback. Ea stages of dieback are indicated by dying twigs and lim with browning leaves. Dieback may occur in just o limb or throughout most of the crown (fig. 20–4). severe cases, when the main stem is affected, sprou

ow from the lower bole and root collar. Similar symp-
ns can be caused by other fungi, severe droughts, and
emical injury. Associated fungi and environmental
nditions should be carefully investigated when at-
npting to identify the causes of dieback.

. *theobromae* fruits on infected tissue but may sapro-
ytically colonize and fruit on dead wood. Pycnidia,
fruiting bodies, are black and about the size of a
nhead. They are embedded in the outer layer of dead
rk. Conidia produced by pycnidia must be observed
croscopically for positive identification. In addition
identifying the fungus by pycnidial production on
ad wood, cultures should be made from the advanc-
g edges of cankers and dieback. *B. theobromae* and
ner canker fungi can be cultured on potato dextrose
ar.

sease Cycle

onidia from *B. theobromae* pycnidia on dead bark are
e primary inoculum for new infections. They are
spersed by wind, but can also be carried by insects,
lashing rain, or pruning tools. When conidia make con-
t with suitable infection courts, such as wounded
ems and branch stubs, they germinate and colonize
st tissues.

olonization does not always result in a canker. Sus-
ptibility of the tree involved, virulence of the fungus
ain, and environmental conditions are determining
ctors for canker formation. The most virulent strains
n cause cankers in non-stressed trees, but the least
rulent strains do not. Canker development is favored
high temperatures and waterstress. Conidia are again
oduced on established cankers, and the infection proc-
s is repeated if environmental conditions are favorable.

amage

The effects of infection can range from small, in-
nspicuous cankers to tree mortality. Small cankers
allus over" and have little effect on trees. Large
nkers slow the rate of growth, cause wood defects, and
eaken stems to make trees more vulnerable to wind-
eakage. Dieback changes the growth pattern and form
individual trees. Forked terminals result from apical
eback. Severe dieback and/or cankering may kill trees.

ontrol

Losses from Botryodiplodia cankers can be reduced
cultural practices. Avoid wounding stems and mak-
g branch stubs. Prune during late fall or winter when
lonization by *B. theobromae* is lessened because of low
mperatures. Avoid planting on poor and dry sites
cause waterstress favors infection and disease develop-
ent. Shade trees should be watered during periods of
ought. When possible, plant seedlings that are adapted
a particular geographic or climatic site. The seed
urce should be local if possible. Use genetically im-
roved stock with resistance to Botryodiplodia cankers
hen available.

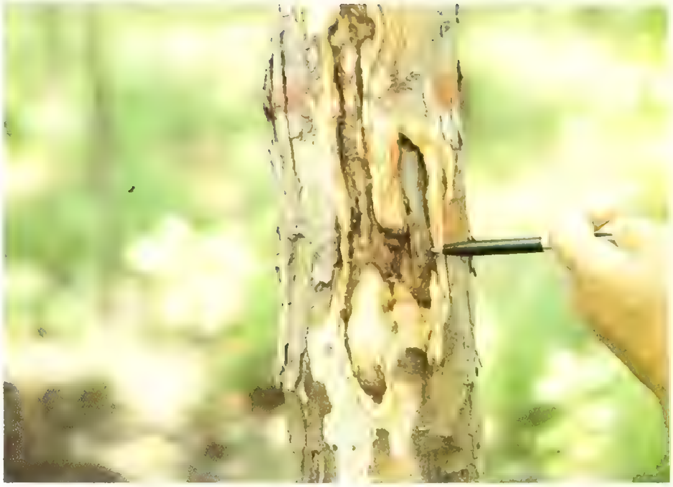


Figure 20-3. Old inactive canker surrounded by callus.

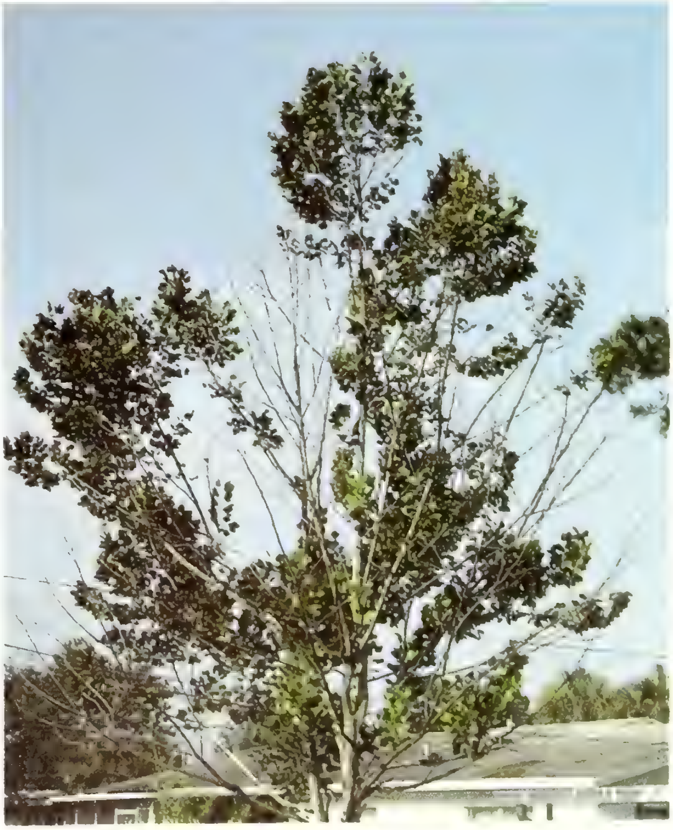
Selected References

Filer, T. H., Jr. Sycamore cankers caused by *Botryodiplodia theobromae*. Phytopathology. 59: 76–78; 1969.

Lewis, R., Jr. Influence of infection court, host vigor, and culture filtrates on canker production by *Botryodiplodia theobromae* conidia in sycamore. Plant Disease Reporter. 62: 934–937; 1978.

Thompson, G. E. Die-back of sycamore. Plant Disease Reporter 35: 29–30; 1951.

Figure 20-4. Dieback of twigs and limbs.



21. Cytospora Canker of Cottonwoods and Willows

James A. Walla and Kenneth E. Conway

Cytospora canker, caused by *Valsa sordida* (asexual stage, *Cytospora chrysosperma*), is a common disease of poplars and willows in the Great Plains. *Cytospora* spp. can be saprophytes; they commonly colonize bark and twigs that have been killed by other causes.

Hosts and Distribution

Cytospora canker is widespread in North America. It occurs on most species of *Populus* and *Salix* throughout their range, and on many other hosts. Resistance to *Cytospora* varies among hosts.

Symptoms and Signs

Cytospora causes branch dieback and cankers on trees of any age. Cankers on trunks and limbs are often elongate, slightly sunken, discolored areas in the bark (fig. 21–1). Bark often splits along the canker margin because of callus formation by the host. The fungus may quickly girdle and kill twigs without forming cankers. Symptoms vary with mode of entry, host species affected, and stage of disease development. Infected bark may be yellow, brown, reddish-brown, gray, or black. Diseased inner bark and cambium turns reddish-brown to black, and becomes watery and odorous as it deteriorates. Wood below the cankered bark is stained brown.

Fruiting bodies develop in dead bark. Asexual fruiting bodies (pycnidia) form first and appear as small pustules on smooth bark (figs. 21–1, 21–2). Pycnidia are less conspicuous on rough bark. Superficial cuts in cankered bark will expose small (0.5–1.5 mm dia.) black pycnidia During moist weather, yellow to reddish-brown spore masses or tendrils may exude from pycnidia (fig. 21–3) The spores (conidia) are hyaline, allantoid, one-celled and 3–5 by 1–1.5 μm.

Sexual fruiting bodies (perithecia) are sometimes found in bark after pycnidia mature. Perithecia are smaller (0.3–0.5 mm dia.) than pycnidia and are grouped (6–12) in a black stroma (2–8 mm dia.). The upper surface of the stroma breaks through the bark to expose a dark gray disk (fig. 21–4). Ascospores from perithecia are hyaline allantoid, one-celled, and 7–12 by 1.5–2.5 μm.

Disease Cycle

Spores from fruiting bodies are dispersed by rainsplash, wind, insects, or birds. *Cytospora* infects only

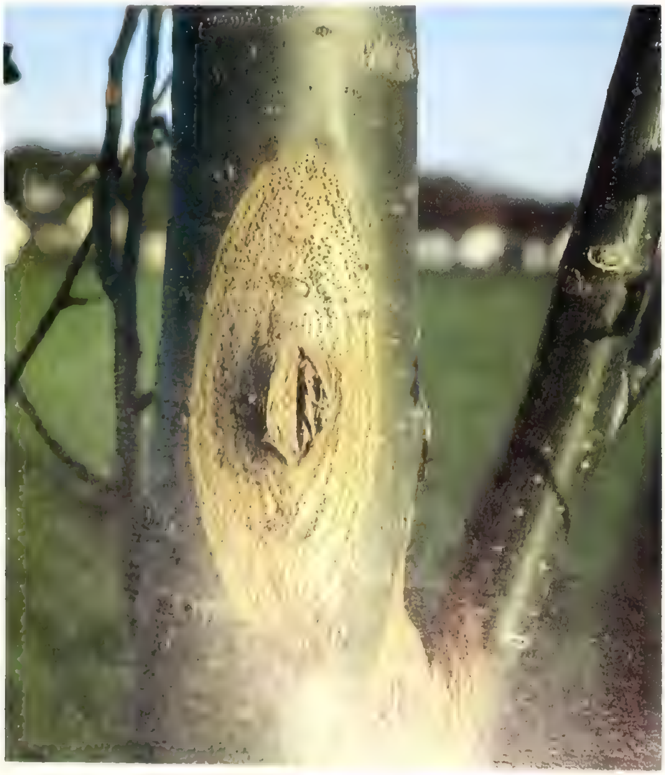
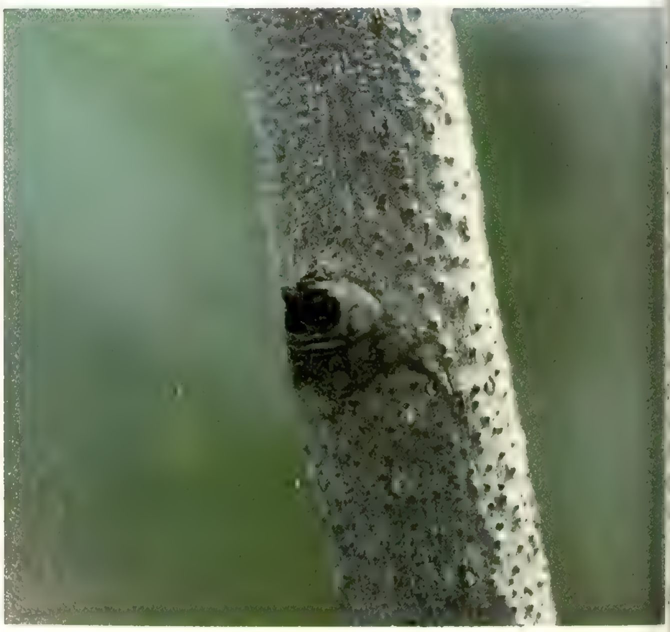


Figure 21-1. Cytospora canker on stem of poplar, showing pycnidia and discolored bark.

Figure 21-2. Pycnidia of *Cytospora* on a rapidly killed stem of cottonwood without the formation of a definite canker.



through wounds or other openings in the bark. It is considered a weak parasite, and most often attacks stressed trees, such as those growing on poor sites or injured by drought, frost, sunscald, severe pruning, fire, insect or mechanical damage, or herbicides.

The fungus grows in the bark until limited by internal processes of the tree. Fruiting bodies form in infected bark to complete the life cycle. The fungus overwinters as fruiting bodies and mycelium in cankered bark.

Cytospora has been found in apparently healthy bark; thus it may be able to infect bark tissue and remain there without causing visible damage until the tree is stressed.

Damage

Cytospora can cause dieback or death of planted or native trees. It is a limiting factor in the establishment and growth of some poplars and willows. In nurseries, it can attack cuttings of poplars and willows that are used for propagation. A disease called blackstem is caused by *Cytospora* and other canker fungi; it can develop during storage or after outplanting (fig. 21–5) and can result in severely reduced nursery production.

Control

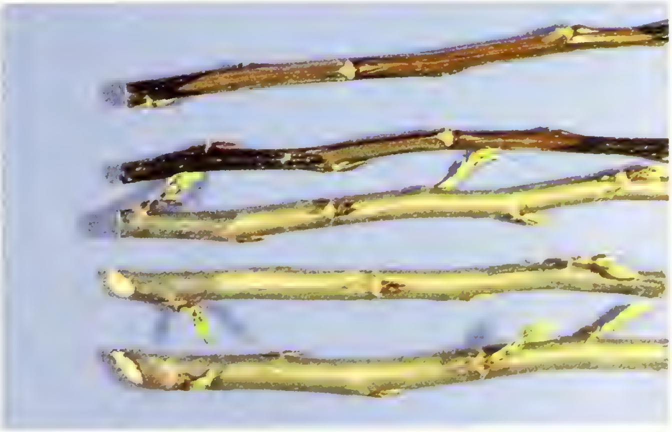
Healthy trees are less susceptible to infection and damage. If possible, water and fertilize trees as needed to maintain optimum vigor. Reduce chances of infection by preventing wounds. Do not bring infected plant materials into the area. Plant resistant varieties.

Trees that usually are not resistant to *C. chrysosperma* include various species (eastern cottonwood, white cottonwood, weeping willow), varieties (Lombardy and Bolleana poplar), and the selection Siouxland cottonwood. Those usually resistant include the hybrid poplar Noreaster, certain eastern cottonwood selections (Platte, Mighty Mo, Ohio Red), and the species valley cottonwood, and black and peachleaf willow. Norway poplar s relatively resistant to blackstem.

Severely cankered branches or trees should be removed and destroyed. Prune back to a live branch beyond the canker. Small cankers on stems can be removed by excising all affected bark. Shape wounds nto an ellipse to promote rapid healing. Prune during dry weather. Disinfect pruning tools with alcohol after each cut.

A systemic fungicide is labeled for Cytospora canker control. Protective fungicides are registered for control of wound fungi on trees but are not specifically labeled or Cytospora.

To avoid cankers on nursery cuttings, maintain healthy tock blocks. Collect shoots from stock blocks in the fall efore very cold weather causes bark moisture to fall. Process and store cuttings quickly: dip cuttings in a ungicide solution before winter storage, store at a contant temperature below 35°F, and plant cuttings in beds fter soil warms to allow rapid plant growth.



gure 21-5. Poplar cuttings with necrotic tissue typical of blackstem caused by *Cytospora*.

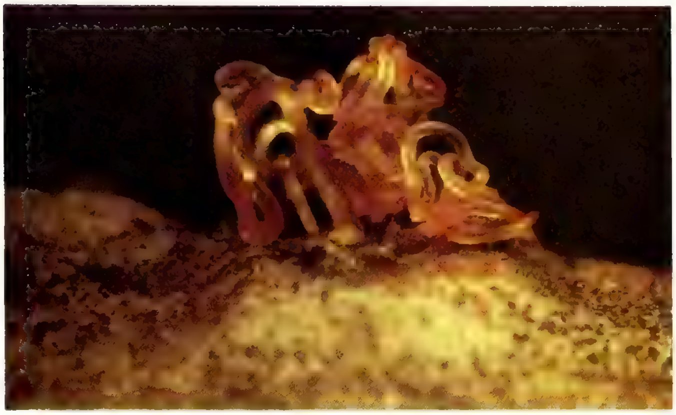
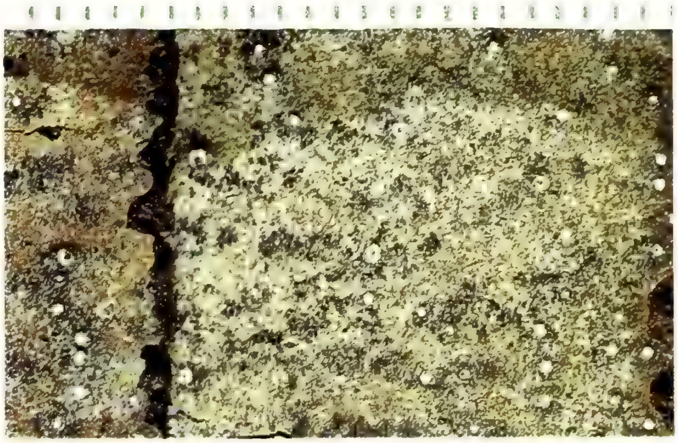


Figure 21-3. Spore tendril from pycnidium of *Cytospora*.

Figure 21-4. Perithecia with gray disk typical of *Valsa* spp. (scale in mm).



Selected References

Bloomberg, W. J. Cytospora canker of poplars: factors influencing the development of the disease. Canadian Journal of Botany. 40: 1271–1280; 1962.

Walla, J. A.; Stack, R. W. Dip treatment for control of blackstem on *Populus* cuttings. Plant Disease. 64: 1092–1095; 1980.

Wysong, David S.; Riffle, Jerry W. Cytospora canker of poplars and willows. NebGuide G75-257. Lincoln: Cooperative Extension Service, University of Nebraska; 1982. 3 p.

22. Septoria Canker of Cottonwood and Hybrid Poplars

Jerry W. Riffle and David S. Wysong

Septoria musiva causes leaf spots and cankers on native and hybrid poplars. Information on the leaf spots caused by this fungus appears in Article 3.

Hosts and Distribution

S. musiva is indigenous throughout much of the United States and Canada. In the Great Plains it occurs in North Dakota, Nebraska, and Texas. The fungus produces cankers on native cottonwood (*Populus deltoides*), and on a wide range of hybrid poplars, particularly those of cottonwood, balsam poplar (*P. balsamifera*), or black poplar (*P. nigra*) parentage. In the north-central region of the United States, hybrids with a parent of Japanese poplar (*P. maximowiczii*), black cottonwood (*P. trichocarpa*), or laurel poplar (*P. laurifolia*) are very susceptible.

Symptoms and Signs

Cankers are formed on the main stem and branche of the current season's growth, usually within 5 feet c the ground. Cankers are often flat-faced, or have swolle marginal callus. The bark of young cankers is dar brown or black and depressed (fig. 22–1). Infected can bium is killed, and small black pycnidia may develop i bark in the ashy-white central area of the canke (fig. 22–2). Continued development of cankers may resu in girdling and death of affected stems during late sum mer. Affected stems may be infected by other canke fungi, such as *Cytospora chrysosperma*, that cause add tional damage.

Two types of spores form in fruiting structures in ir fected host tissues. Conidia (pycnidiospores) develop i

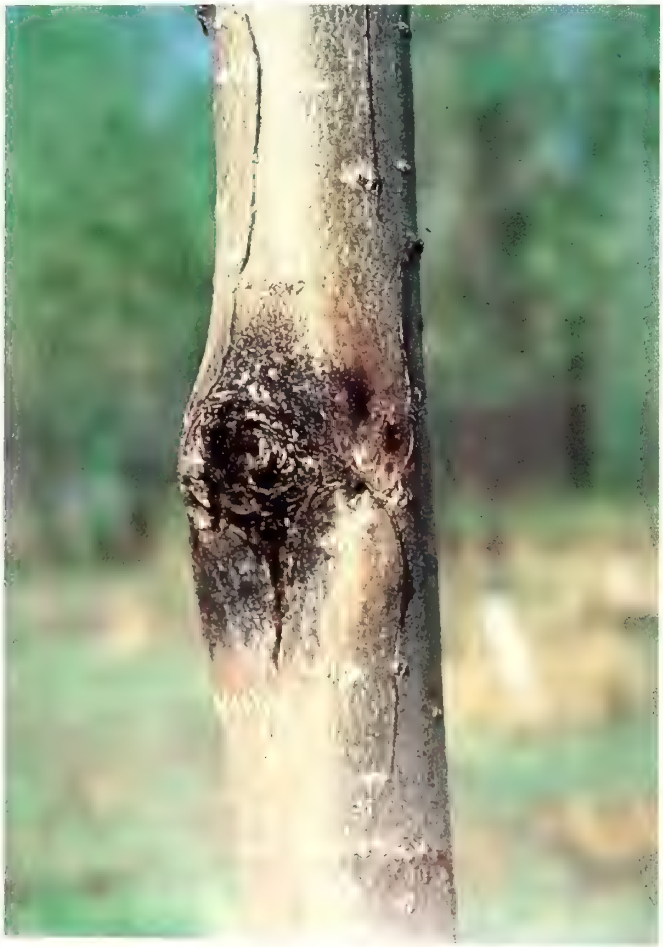


Figure 22-1. C. [illegible] tree.

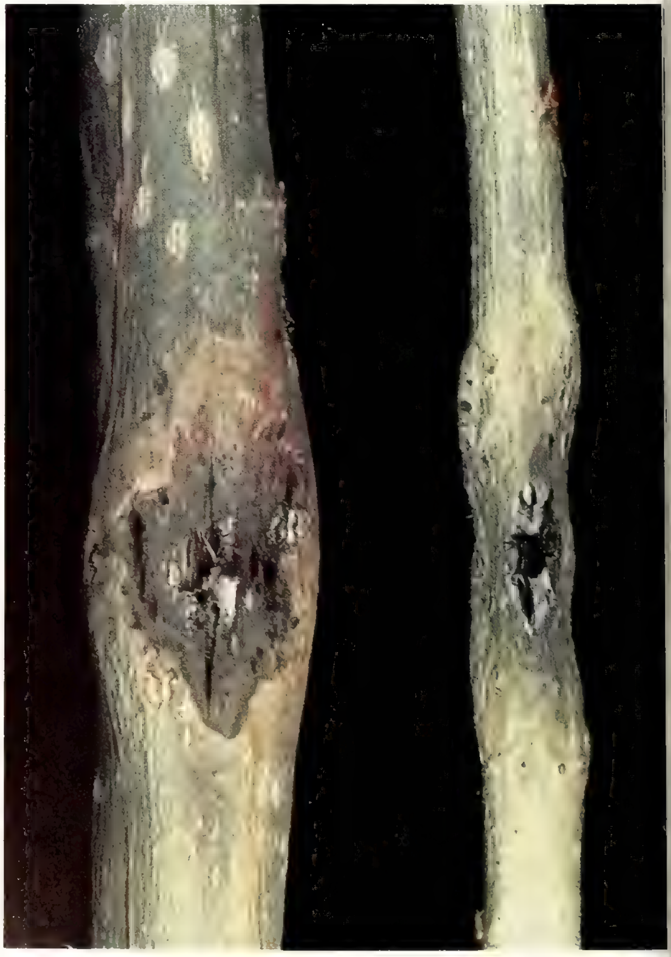


Figure 22-2. Depressed cankers on cottonwood cuttings. Pycnidi develop on bark in the central area of young cankers.

pycnidia on bark or leaves, and exude in pink or white tendrils during wet weather. Conidia are hyaline, cylindric, straight or curved, one to four septate, and are 20–56 μm long by 3–4 μm wide. Ascospores of the perfect stage *Mycosphaerella populorum* are produced in perithecia that develop on fallen leaves. The ascospores are hyaline, 1-septate, and 16–28 μm long by 4.5–6.0 μm wide.

Disease Cycle

S. *musiva* overwinters on fallen infected leaves and in bark of cankers. In the spring, ascospores and conidia from fallen leaves and conidia from cankers are discharged during wet weather. These spores are dispersed by wind and washed by rain to infect leaves and stems. Both ascospores and conidia can cause stem infections. Infections may occur through stipules (fig. 22–3), petioles, buds, lenticels, or through bark wounds. The fungus also can infect unwounded leaves and stems. Leaf infection usually precedes stem infection. Leaf spots appear soon after leaves develop, and the fungus spreads to stems and branches to form cankers. Cankers are formed on twigs of the current season's growth, and pycnidia develop shortly after infection. Conidia from pycnidia in leaf spots and cankers cause secondary infections. Disease development is enhanced by warm temperatures and long periods of humidity.

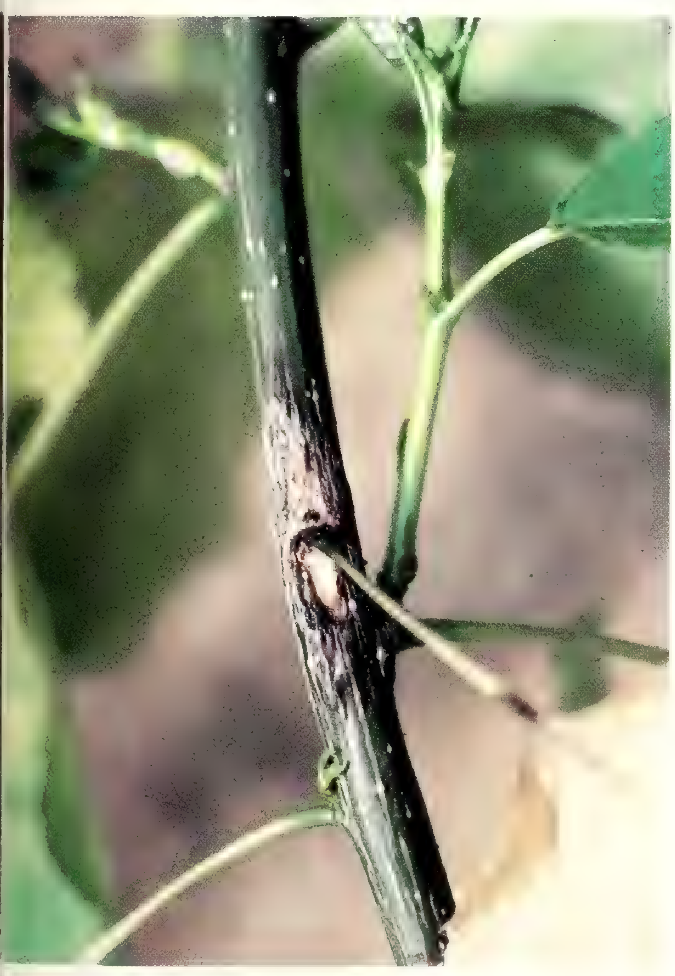


Figure 22–3. Infection of cottonwood stem through leaf stipules and subsequent canker development.

Damage

S. *musiva* damages poplars of all ages, but damage is most severe in nursery stool (propagation) beds and in young plantations. In plantations, growth of the fungus from twigs into main stems results in cankers that girdle small stems of susceptible trees, particularly hybrids. Extensive losses have occurred in hybrid poplar plantings in northeastern States. Multiple cankers can girdle affected stems; single cankers seldom girdle a branch or stem of moderately susceptible trees, but the cankers may be invaded by other fungi that do girdle stems and kill trees.

Control

Damage caused by S. *musiva* is reduced primarily by the use of resistant cultivars. Clones resistant or moderately susceptible to leaf spot also tend to be resistant to cankers, so these clones should be selected for planting. Vigorous, disease free planting stock should be used for establishment and maximum early growth of hybrid poplar.

Fungicides can reduce pathogen populations. Captafol effectively controlled S. *musiva* in a central Iowa planting in tests in 1979–1980. Benomyl applied at one pound active ingredient per 100 gallons of water once in spring and bimonthly throughout the growing season also has controlled S. *musiva* on susceptible clones.

Cultural treatments, such as cultivation or raking in the fall to remove leaf litter containing fungal inoculum, will minimize primary infections in the spring if inoculum from adjacent trees is not a factor. Planting moderately susceptible trees at a wide spacing to provide good air circulation within the canopy will reduce the duration of free moisture on leaves and minimize infection by S. *musiva*.

Selected References

Bier, J. E. Septoria canker of introduced and native hybrid poplars. Canadian Journal of Research, Section C. 17: 195–204; 1939.

Filer, T. H.; McCracken, F. I.; Mohn, C. A.; Randall, W. K. Septoria canker on nursery stock of *Populus deltoides*. Plant Disease Reporter. 55: 460–463; 1971.

Ostry, M. E.; McNabb, H. S. Jr. Diseases of intensively cultivated hybrid poplars: A summary of recent research in the north-central region. In: Hansen, E. A. compiler. Intensive plantation culture: 12 years research. Gen. Tech. Rep. NC–91. St. Paul, MN: U.S. Forest Service, North Central Forest Experiment Station; 1983: 102–109.

Waterman, Alma M. Canker of hybrid poplar clones in the United States, caused by *Septoria musiva*. Phytopathology. 36: 148–156; 1946.

Waterman, Alma M. Septoria canker of poplars in the United States. Circular 947. Washington, DC: U.S. Department of Agriculture; 1954. 24 p.

23. Phomopsis Canker on Cottonwood

Theodore H. Filer, Jr., and Edward M. Sharon

Cottonwood occurs naturally along streams and rivers throughout the Great Plains. In most of its range, cottonwood grows on moist, well drained soils; but in the western semi-arid one-third of its range, it is found only along streams.

Hosts and Distribution

Phomopsis macrospora causes dieback and cankers on many tree species in the United States, as well as in Europe and Japan. The species was first described in Japan in 1961 and in the United States in 1967. The perfect stage of the fungus was first described on willow in 1891. This stage is distinctly different from the perfect stages—*Diaporthe eres* and *D. medusaea* (the predominant species on *Populus*) because of its larger ascospore with appendage and because the alpha spores are larger than the beta spores.

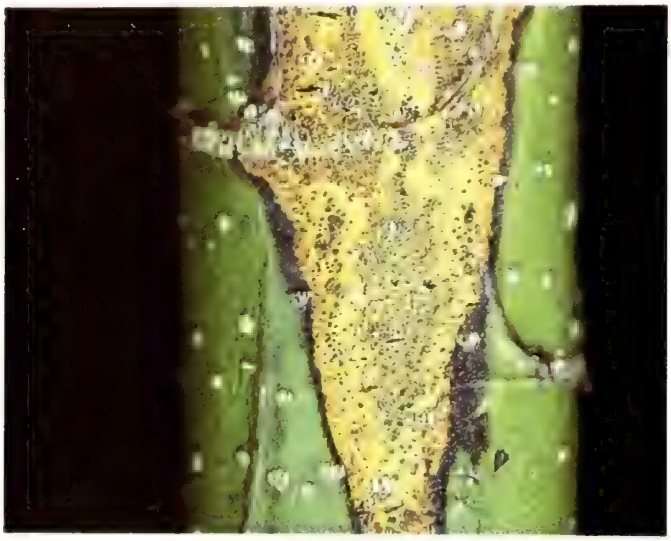
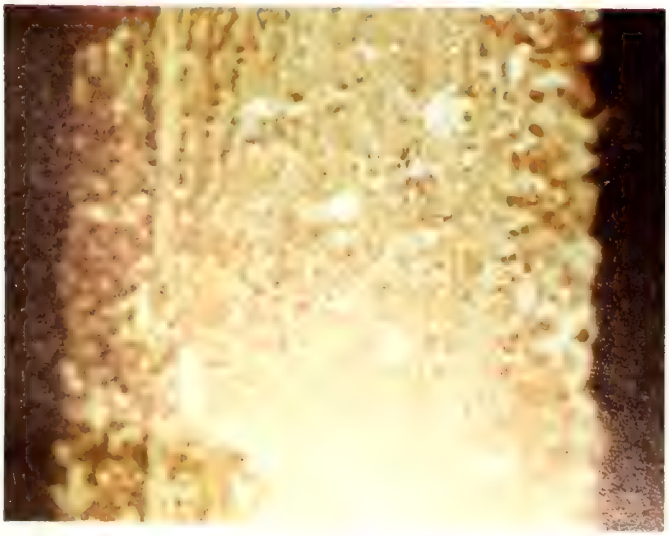


Figure 23-1. Small black pustules of *Phomopsis macrospora* on surface of canker.

Figure 23-2. White curled sporehorns composed of millions of spores that can cause new infections.

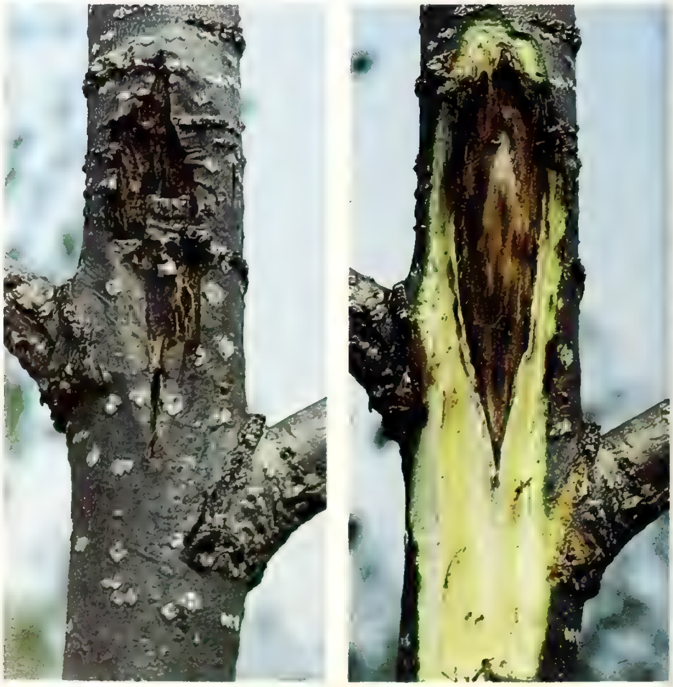


Symptoms and Signs

Phomopsis cankers develop on cottonwood twigs, limbs, and boles; they are inconspicuous during early development. Small pustules on cankers appear as small black dots, protruding through bark epidermis (fig. 23–1). Spores are pushed out of the pore of pustules under moist conditions, and often form sticky orange or reddish sporehorns (fig. 23–2). As the canker develops and enlarges, the phloem tissues die, forming a sunken area (fig. 23–3). When the stem is girdled, the distal portion dies; the resulting dead leaves cling to the branches for several weeks (fig. 23–4). Similar symptoms are caused by *Fusarium*, *Cytospora*, and other canker-causing fungi.

P. macrospora fruits profusely on dead wood. The small black fruiting bodies are less than a millimeter in size. They look like miniature mountains protruding through the bark (fig. 23–5).

Figure 23-3. (a) Sunken area inside canker. (b) Canker 23-3a with outer bark removed to show necrotic tissues.



Disease Cycle

The asexual spores are the primary inoculum. Conidia are primarily wind- and insect-dispersed, but rain can spread the spores to wounds on lower parts of the tree. The fungus is considered a wound parasite, and needs some natural or wound opening before it can penetrate and colonize tissues. The size of canker that develops depends on tree vigor. On fast-growing cottonwoods, canker development is usually limited and the callus tissue formed restricts fungal growth. On slow-growing trees (trees growing under moisture stress or in poorly aerated soils), cankers can girdle the stem and cause mortality.

Damage

Phomopsis is one of the most important pathogens that cause mortality of planted cuttings. In most cases the fungus is on the cuttings when they are taken from the nursery, and girdles the stem within a few weeks after planting.

Control

Good cultural practices can reduce the possibility of mortality of shade trees. Fertilize trees at the rate of 6 pounds of N-P-K per 1,000 square feet, water at the rate of 2 inches per week during droughty periods, and control insect defoliators and leaf diseases to reduce tree stress and promote tree vigor.

To prevent losses when planting poplars, select healthy, canker-free cuttings or seedlings. Prevent cuttings from drying in storage; soak them at least 24 hours prior to planting. Cultivation is needed during the first year to keep trees growing vigorously. Plant poplars that are resistant to Septoria leaf disease.

Selected References

Filer, T. H., Jr. Pathogenicity of *Cytospora, Phomopsis,* and *Hypomyces* on *Populus deltoides.* Phytopathology. 57: 978–980; 1967.

Filer, T. H., Jr. Cottonwood cankers caused by *Phomopsis macrospora.* (Abstract) Phytopathology. 57: 458; 1967.

Fowells, H. A. Silvics of forest trees of the United States. Agric. Handb. 271. Washington, DC: U. S. Department of Agriculture; 1965. 762 p.

Kobayashi, T.; Chiba, O. Fungi inhabiting poplar in Japan. In: Bull. 130. Tokyo: Government Forest Experiment Station; 1961: 1–43.

Morris, R. C.; Filer, T. H.; Solomon, J. D.; McCracken, F. I.; Overgaard, N. A.; Weiss, M. J. Insects and diseases of cottonwood. General Technical Report SO–8. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1975. 37 p.

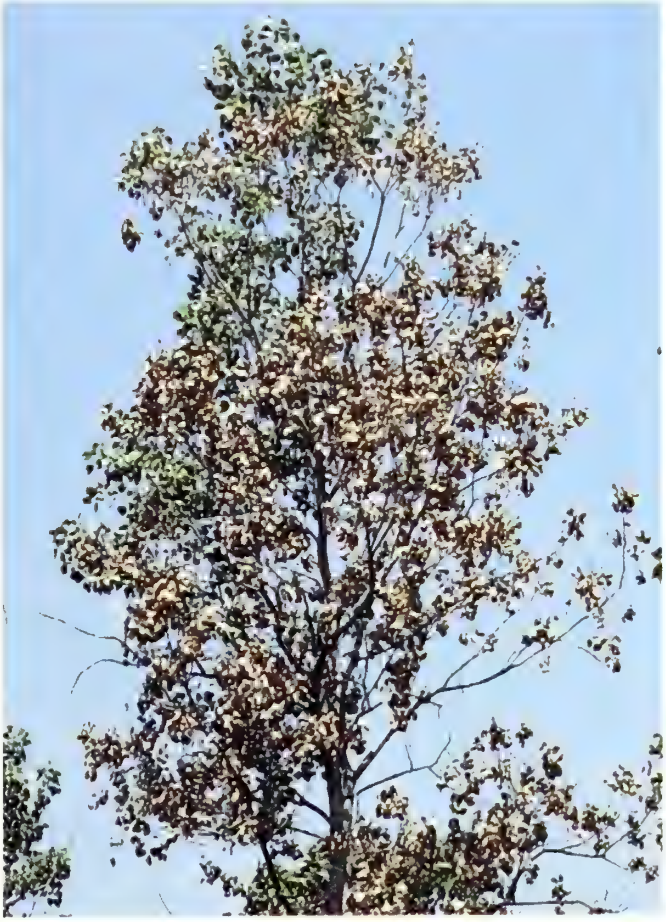
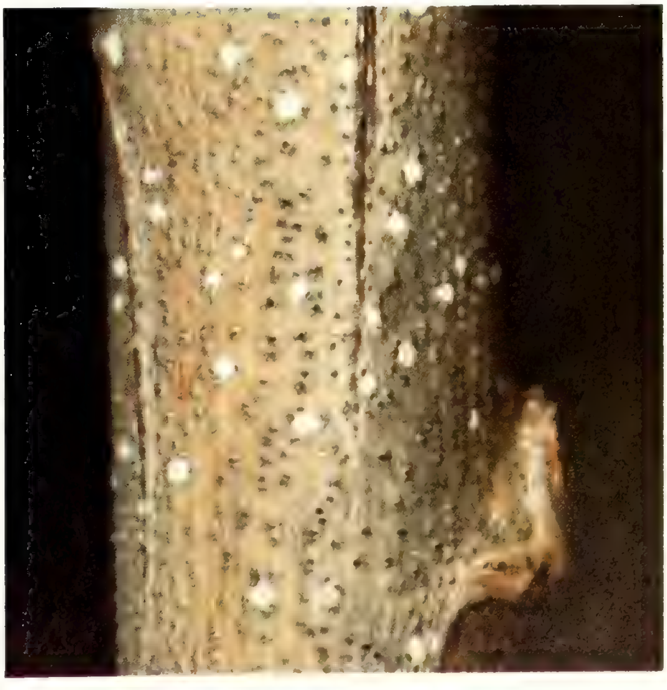


Figure 23-4. Crown of cottonwood showing dead leaves on branches girdled by cankers.

Figure 23-5. Small black fruiting bodies of *P. macrospora* protruding through bark.



24. Dothichiza Canker of *Populus* species

David W. Johnson and Robert W. Stack

Hosts and Distribution

Canker of poplars caused by *Dothichiza populea* has been known in the United States since 1915. The disease is most common in nurseries and plantations in the eastern and central States. *D. populea* infects a wide range of *Populus* species and hybrids, especially those in the Tacamahaca and Aegieros groups; Lombardy poplar is particularly susceptible. It has also been reported on quaking aspen and bigtooth aspen. The range of *D. populea* extends from Maine to Virginia and westward to Minnesota, Nebraska, and New Mexico. It occurs on young trees in nurseries and plantations, but is rare or of little significance in native stands.

Symptoms and Signs

Early symptoms are a premature yellowing of the leaves, followed by defoliation. Girdling cankers cause dieback of small stems and shoots. The development of cankers varies greatly with host age and species. Young trees may be girdled rapidly, which causes topkill. Poplar with large spreading branches and those resistant to the fungus may only develop small branch cankers.

In general, cankers first appear as slightly sunken areas with the diseased bark slightly darker than healthy bark (fig. 24–1). After the bark is killed to the cambium, the sapwood is invaded and turns brown. Cankers develop during the dormant season. As the canker develops, the bark cracks and extensive callus is produced (fig. 24–2).

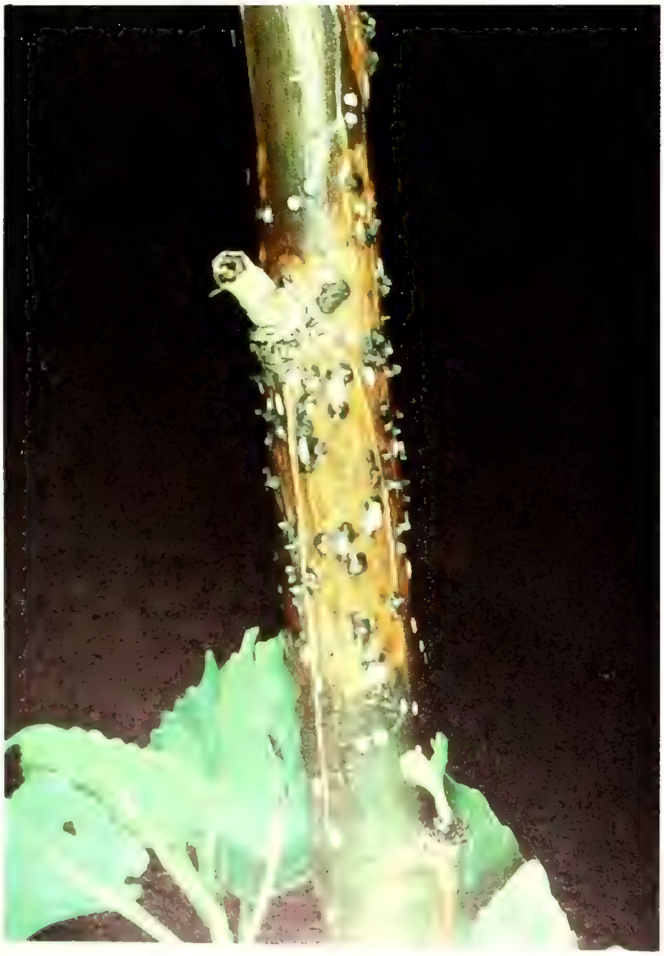


Figure 24-1. Young Dothichiza canker with discolored bark.

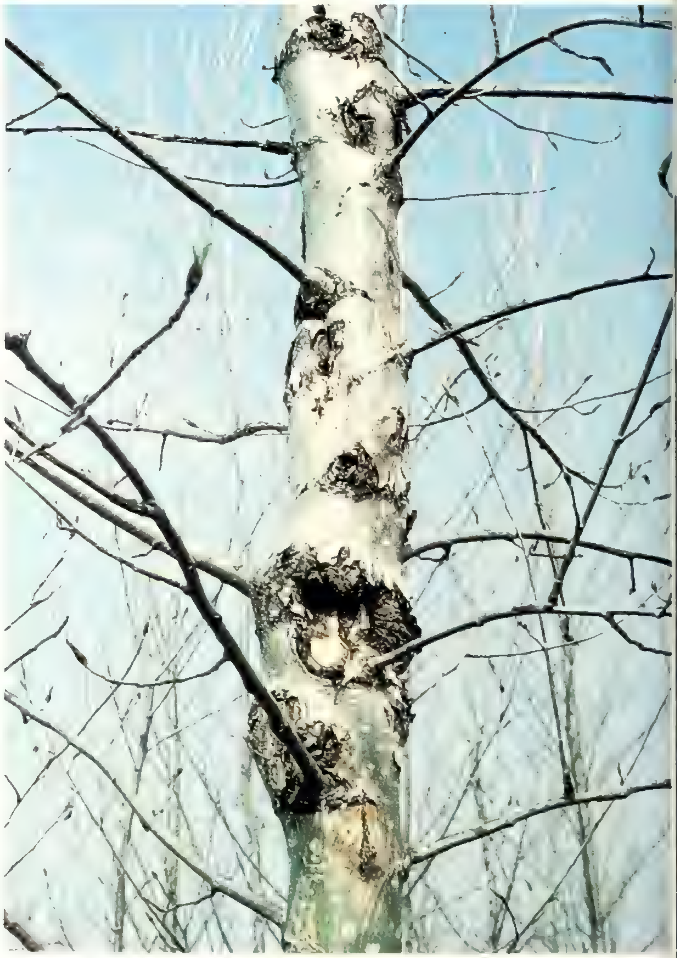


Figure 24-2. Extensive callus development associated with Dothichiza stem cankers.

Sprouts may develop below dead limbs and cankers. These sprouts may be killed in following years.

Cushion-like fruiting bodies called pycnidia are formed on the dead or wilting twigs (fig. 24–3). In time the diseased bark turns brown and cracks, and the underlying dark brown, diseased wood is exposed.

Disease Cycle

D. populea overwinters as spores in unopened pycnidia and as mycelium within the bark tissue. In the spring new pycnidia, when mature and moisture conditions are favorable, rupture the bark and extrude spores in olive-buff tendrils or in masses. Conidia are unicellular, hyaline, and ovate pyriform to spherical (fig. 24–4). They are washed about by rain or carried by insects or birds. Possibly, after the spore tendrils dry, some are wind-borne. New pycnidia may be formed as the dieback and canker enlarges, so that mature spores may be present throughout the summer and fall.

The fungus may infect through bud scales, leaf scars, or bark at the base of small lateral twigs into a stem or branch. Cankers develop around the base of twigs or injured buds. The fungus also infects leaf scars following early defoliation by Melampsora rust or Marssonina leaf blotch.

The perfect stage, *Cryptodiaporthe populea*, is reported from Europe but is not known in the United States.

Damage

In Europe the fungus has been recognized as an important pathogen of poplars since 1903, particularly on young or newly planted trees, or on trees that have been weakened by low spring temperatures, poor drainage, drought, pruning wounds, or infertile soil.

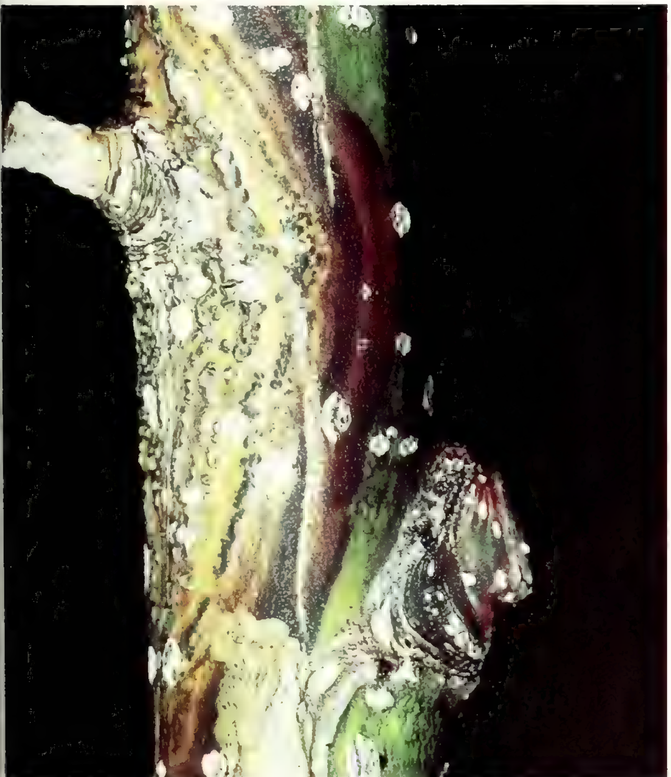


Figure 24-3. Pycnidia develop on dying bark of affected twigs.

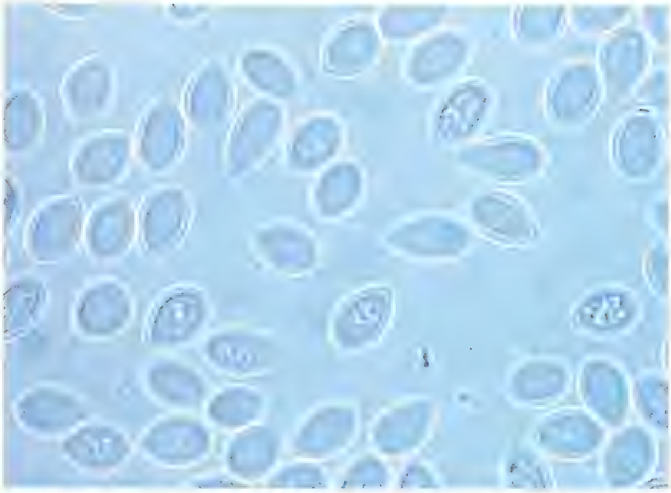


Figure 24-4. Conidia of *D. populea* are hyaline, unicellular, and ovate pyriform to spherical.

Although the disease is endemic in the United States, it has not been as damaging as in Europe; however, its potential for damage in plantations is a concern.

Control

The disease has not been sufficiently severe in the United States to warrant a detailed study of control measures. Because of the possibility of infection in plantations, care should be taken to use disease-free stock for planting and to maintain good growing conditions. Infected stock should be destroyed. Applications of excess nitrogen and dense nursery beds should be avoided. Leaf diseases caused by *Melampsora* and *Marssonina* should be controlled in the nursery with fungicides. Choice of planting site is important so that the trees are adapted to the site. Pruning should be avoided if possible, and care exercised to prevent other wounding. Older stands should be thinned. Highly susceptible cultivars such as Lombardy should not be planted.

Selected References

Carter, J. Cedric. Diseases of Midwest trees. Special Publication 35. Urbana: University of Illinois Press; 1979. 168 p.

Gremmen, J. Research on Dothichiza-bark necrosis *(Cryptodiaporthe populea)* in poplar. European Journal of Forest Pathology. 8: 362–368; 1978.

Ostry, Michael E.; McNabb, Harold S. Jr. How to identify and prevent injury to poplars caused by Cytospora, Phomopsis, and Dothichiza. HT–57. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 6 p.

Waterman, Alma M. Canker and dieback of poplars caused by *Dothichiza populea*. Forest Science. 3: 175–183. 1957.

25. Cryptosphaeria Canker of Cottonwood and Aspen

Thomas E. Hinds and Jerry W. Riffle

The genus *Populus* is widespread throughout the Great Plains; five of the nine species native to the United States are found from Texas northward to North Dakota. Of the numerous pathogens known to attack poplars, *Cryptosphaeria populina* is a relatively new stem canker pathogen found on poplars in the Great Plains.

Hosts and Distribution

Although aspen is the principal host of *C. populina*, its occurrence and distribution on other poplars is becoming more apparent because of its recognition. The fungus has been found on narrowleaf cottonwood in Colorado, on Plains cottonwood in Colorado, Oklahoma, and Nebraska, on Lombardy poplar in Nebraska, and on aspen in South Dakota. Other hosts of the fungus include balsam and black poplar, and some hybrid poplars. The proper identification of this organism will no doubt extend its distribution and host range.

Symptoms and Signs

C. populina causes a stem canker that results in branch and tree mortality. Extensive discoloration and decay are attributed to the asexual stage, *Libertella* sp. The cankers, frequently associated with wounds, are long, narrow, and found on the trunk of hosts (fig. 25–1). They may be only 2 to 4 inches wide, but up to 10 feet in length, following the grain of the underlying wood. Cankers may grow up to an inch in width and many inches in length annually. Small trees usually die several years after being infected and before the trunk is girdled. Although branch infection does not always result in a prominent canker, the fungus will spread from a branch infection onto the trunk.

Cryptosphaeria populina colonizes the heartwood and sapwood, and causes extensive discoloration and decay. Various hues of gray, brown, yellow, and orange are associated with the brown-mottled decay, from which the *Libertella* stage of the pathogen is easily isolated. The fungus grows outward to the cambium and bark tissues, causing necrosis and canker formation. The infected bark becomes light brown to orange. After one or more years, the dead bark becomes black, stringy, and sootlike; however, it contains small (0.5–2.0 mm), scattered, lens-shaped, light-colored areas (fig. 25–2), and adheres tightly to the sapwood. This black, adhering dead bark with light

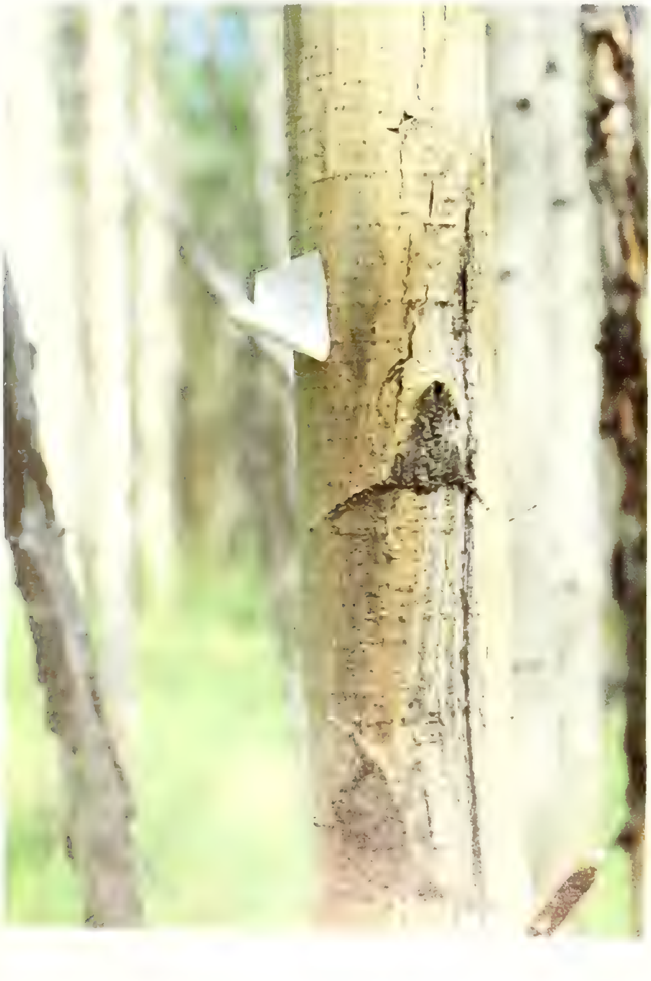
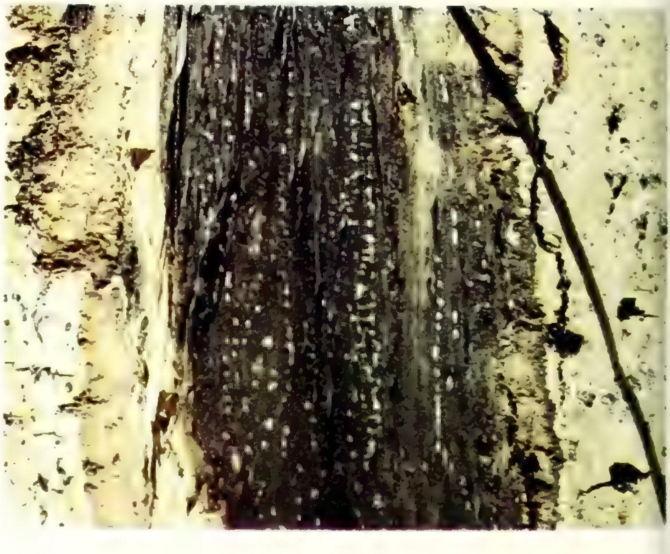


Figure 25-1. Elongated canker on aspen caused by *Cryptosphaeria populina*.

Figure 25-2. Lens-shaped, light-colored areas in the black, dead bark of the canker.



ecks is a good diagnostic characteristic of this canker sease.

Perithecia are formed in a confined area in the dead rk that is raised on the surface in the form of a flat, oad blister that may vary from 0.3 inch in width and to 1-foot in length (fig. 25–3). The fungus readily pro- ces fruiting bodies on branches and smooth bark, but is somewhat limited in penetrating and fruiting on the ick, rough bark of older trees. Light-orange fruiting dies (acervuli) of the *Libertella* stage are occasionally und near the perimeter of cankers on aspen.

Cytospora chrysosperma frequently produces fruiting dies along the canker perimeter and quickly colonizes e dead bark after the branch or tree dies. Because *tospora* fruiting bodies are very conspicuous on the ad tissue, it is often erroneously assumed to be the imary causal agent of the canker.

sease Cycle

Branch and trunk infections become established in ounds to the bark and xylem. The sapwood is colon- d by the pathogen, which causes discoloration and cay; consequently, the cankers seldom completely dle the stem before stem death (fig. 25–4). Perithecia m in the spring on bark tissues that have been dead least one year and mature during the summer and fall their formation. Perithecia persist in the dead bark several years and produce viable spores. Ascospores pelled from the perithecia are apparently wind dis- rsed. Size and shape of *C. populina* ascospores are nilar to *Cytospora* conidia, but they are somewhat ger (8–10 by 2 μm vs. 3–5 by 1–5 μm) and vary from aline to pale yellow. Their similarity to *Cytospora* ores may have contributed to misidentification of the usal agent of the canker in the past.

mage

Saplings and small trees can be killed before cankers d perithecia are produced. Trees weakened by branch d trunk decay are vulnerable to wind breakage. In a 77 study of Colorado aspen, the canker was present 83 percent of 30 sites examined, on 1 percent of the 73 live trees, and was responsible for 26 percent of tree mortality encountered. The importance of this ease of poplars in the Plains is presently unknown.

ntrol

No direct control measures are known. The preven- n of trunk wounds and pruning of dead, dying, or eased branches on high-value trees should aid in ducing the incidence of disease.

lected References

nds, Thomas E. Cryptosphaeria canker and Libertella decay of aspen. Phytopathology. 71: 1137–1145; 1981.

zwik, J.; Nishijima, W. T.; Hinds, T. E. Survey of aspen cankers in Colorado. Plant Disease Reporter. 62: 06–910; 1978.

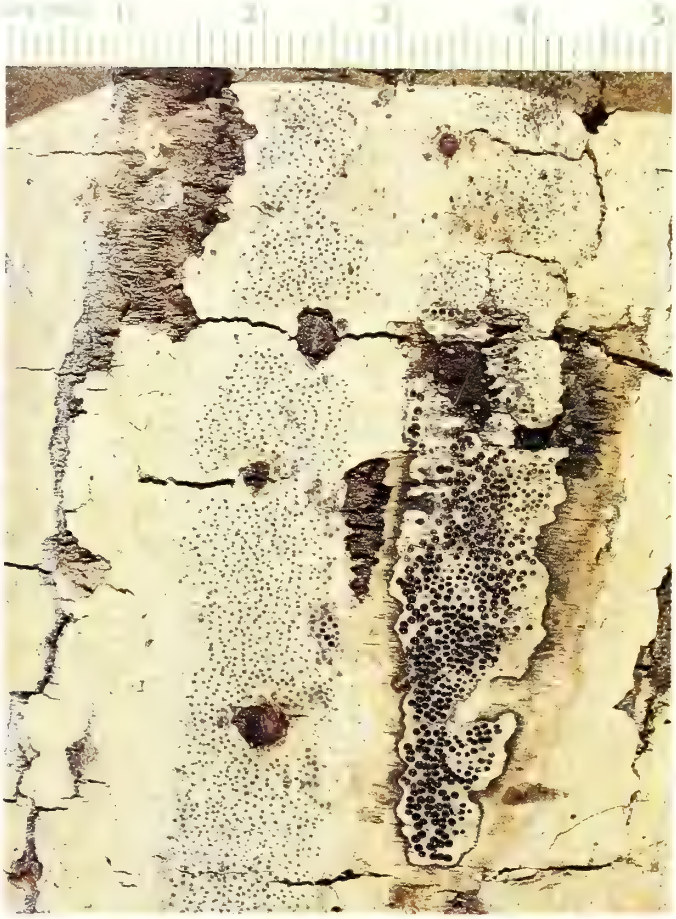
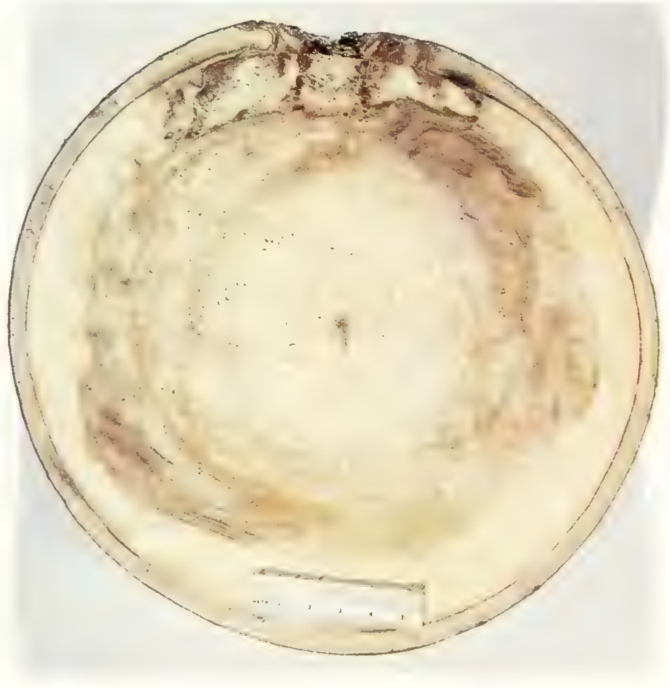


Figure 25-3. Formation of new perithecia in dead bark (left); periderm removed (right) to show perithecia formed the previous year (scale in cm).

Figure 25-4. Discoloration and brown-mottled trunk decay of aspen behind a canker (scale in cm).



26. Hypoxylon Canker of Aspen

Thomas E. Hinds and Mark O. Harrell

Aspen is the most widely distributed forest tree in North America. While the tree is found in the northern States from Maine to Washington and as far south as Mexico in the West, its occurrence in the Great Plains region is sporadic, with small stands in Nebraska, North Dakota, and South Dakota.

Hosts and Distribution

Hypoxylon canker (fig. 26–1), caused by *Hypoxylon mammatum*, is abundant east of the Rocky Mountains; it is the most important killer of aspen in the Great Lakes region. The canker is of minor importance in the tree's western range. Although the disease is present in aspen stands of the northern Great Plains, its importance is unknown.

Quaking aspen is very susceptible, bigtooth aspen is occasionally infected, and balsam poplar is rarely infected.

Symptoms and Signs

Incipient cankers appear as slightly sunken, yellowish-orange areas with irregular, lobed margins centere
around wounds, dead branch stubs, or insect injuries an
galls. As the infection progresses, the affected bar
becomes mottled. A slight flow of sour-smelling brownish sap is common around the perimeter of infection
Small, blisterlike patches are formed under the oute
dead bark during the second year of infection. The bar
then ruptures, exposing small, bristlelike structure
called hyphal pegs or pillars, upon which the spore
bearing structures are formed (fig. 26–2). The structure
soon disintegrate. The diseased inner bark become
laminated or mottled black and yellowish-whit
(fig. 26–3); white mycelial fans are formed near th
canker margin under the bark.

Cankers are easier to identify 2 or 3 years after infec

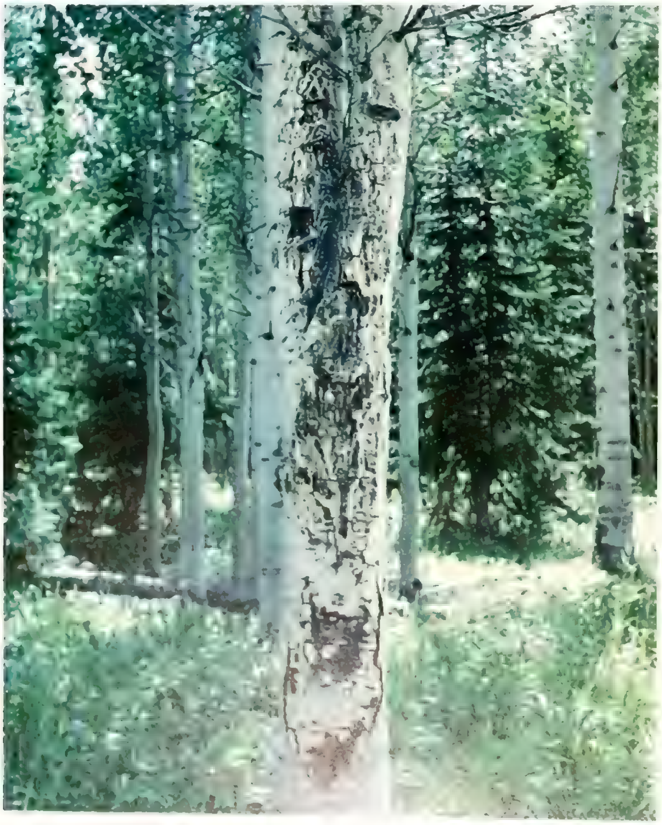


Figure 26-1. Canker initiation [illegible] aspen.

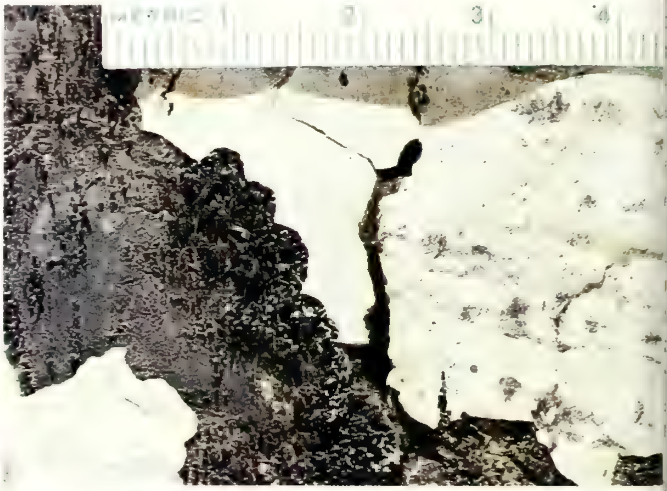


Figure 26-2. Hyphal pegs beneath blistered bark (scale in mm)

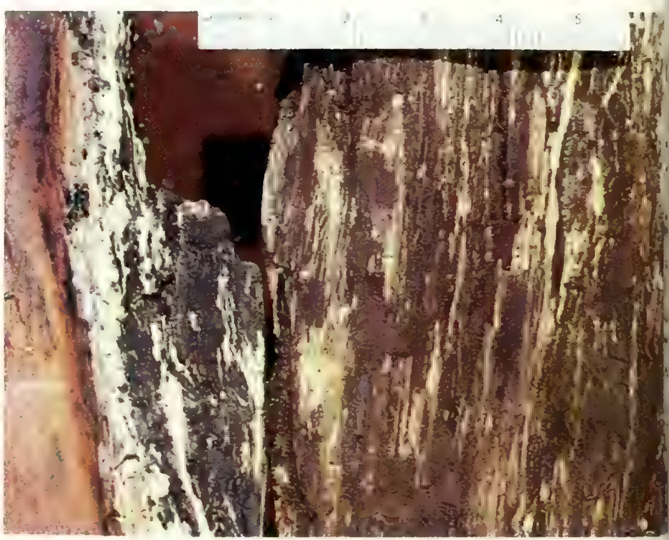


Figure 26-3. Mottled black and yellowish-white diseased inner bar

tion, when perithecia are formed in small, crustlike stromata several mm in diameter on the dead bark (fig. 26–4). The grayish to black stromata appear to be partially covered with a white, flourlike material. The stromata are formed annually on the dead bark, and persist for several years.

Although the tree produces callus tissue at the margin of the infection, the fungus continues to invade new tissue each year. This invasion cracks the bark along the canker margins and leaves the dead bark in a slight depression. The black, dead bark in the center of older cankers begins to crack in a checkerboard fashion and sloughs off in small patches, revealing a checkering of the wood beneath (fig. 26–5). Older trunk cankers may be 3 feet or more in length before the trees are girdled and killed, usually within several years. The roughened, spotted gray and black bark of cankered trees stands out in contrast to the healthy bark of noninfected trees.

Disease Cycle

The fungus is a wound parasite, but the means by which infection takes place is unknown. Apparently, airborne spores enter through wounds to the wood, including insect wounds. The fungus colonizes the sapwood, and then invades the bark from within by producing a toxin that causes bark collapse and necrosis.

The asexual stage of the fungus consists of conidiophores and conidiospores, which are produced on the hyphal pegs formed under the bark blisters at the end of the first or during the second growing season. The role of conidiospores in causing new infections is unknown. Between the second and third year of infection, the first immature perithecial stromata of the sexual state are formed on the dead bark. They are generally abundant on older cankers. Ascospore release requires free moisture, usually in the form of dew, rain, or snowfall, and can continue for several years.

Damage

H. mammatum kills 1 to 2 percent of the standing aspen volume each year in the Lake States region by girdling the trees. While this canker disease is not of major importance in the Rocky Mountain region, its impact on aspen in the Great Plains is unknown.

Canker incidence varies with geographic location; the level of infection fluctuates from year-to-year. Tree vigor does not appear to influence host susceptibility. Although older stems are generally more resistant, upper bole infections, usually found on older trees, may partially kill the crown, and ultimately result in tree mortality from suppression. Trees weakened by decay behind cankers in the lower bole are susceptible to wind breakage before canker girdling is complete. Low density stands, mixed stands, thinned stands, and trees on the perimeter of stands are more susceptible to infection than fully stocked stands.

Control

Although no direct control measures are known for Hypoxylon canker, certain silvicultural techniques can reduce canker losses. Because Hypoxylon canker is favored by stand openings and poor stocking, maintaining fully stocked stands and a closed canopy without openings should reduce volume losses.

Other silvicultural management practices advocated for aspen in the Lake States include: (1) if 15 to 20 percent of the trees are infected, harvest the stand early and treat the site to encourage good aspen reproduction; (2) if more than 25 percent are infected, harvest immediately and convert to other species (susceptible clones should not be perpetuated); and (3) lightly infected stands can be managed on rotations longer than 40 years.

Selected References

Anderson, R. L.; Anderson, G. W. Hypoxylon canker of aspen. Forest Pest Leaflet 6. Washington, DC: U.S. Department of Agriculture, Forest Service; 1979. 7 p.

Schipper, A. L., Jr.; Anderson, R. L. How to identify Hypoxylon canker of aspen. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1976. 5 p.

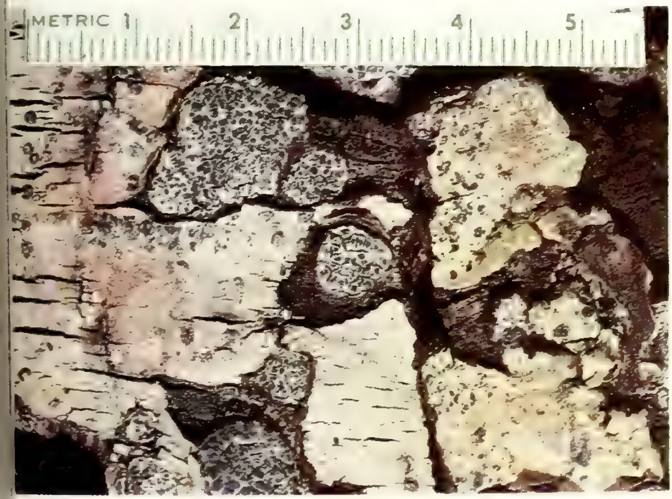


Figure 26-4. Perithecial stromata on dead bark (scale in mm).

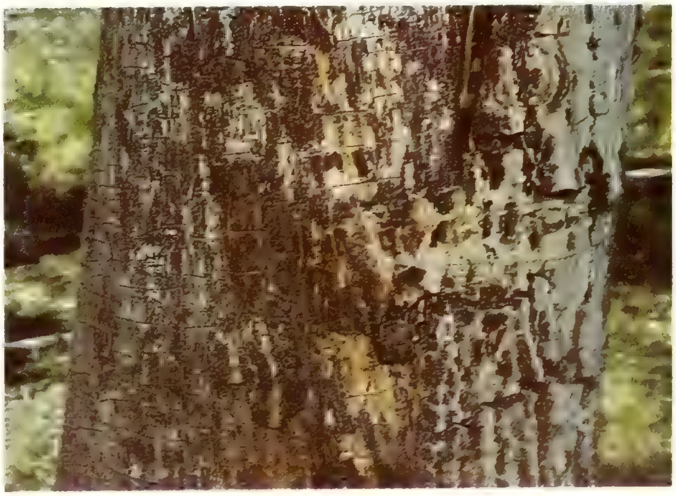


Figure 26-5. Checkering of wood beneath old canker.

27. Thyronectria Canker of Honeylocusts

William R. Jacobi and Jerry W. Riffle

Thyronectria canker is a disease of honeylocusts caused by the fungus *Thyronectria austro-americana*. The imperfect stage of *T. austro-americana* is *Gyrostroma austro-americanum*.

Hosts and Distribution

Native thorny honeylocust (*Gleditsia triacanthos* var. *triacanthos*), all cultivars of thornless and podless honeylocust (*G. triancanthos* var. *inermis*) and oriental honeylocust (*G. japonica*) are susceptible to *T. austro-americana*. The fungus also has been found on dead tissue of several hardwoods including American elm, white ash, mockernut hickory, willow, and bur oak.

The disease has been reported from Colorado to Massachusetts, occurring in Alabama, Colorado, Illinois, Kansas, Massachusetts, Mississippi, Nebraska, Oklahoma, South Dakota, and Tennessee. The disease has not been reported from northern States such as Minnesota or Wisconsin, so fungus distribution may be restricted by colder climates.

Symptoms and Signs

Symptoms include dieback of affected branches, reduced foliage, yellow foliage, premature fall coloration, and early leaf drop. Cankers range from slightly flattened surfaces to distinctly sunken areas with large callus ridges at the canker margin (figs. 27–1, 27–2). Thin bark areas of stems and branches may have a red-yellow discoloration associated with the canker. Usually there is no discoloration where the bark is thicker. Wood beneath infected bark turns wine-red to yellow.

Signs of the pathogen allow for better disease identification than do symptoms. Irregular pycnidia in stroma (stromatic conidiomata) (figs. 27–2, 27–3), which are light yellow-brown when fresh and blacken with age, and perithecia that are reddish-brown or gray but also darken with age, form in the cankered area on dying and dead bark. They are usually found in natural openings such as lenticels in thick bark areas (fig. 27–2), and scattered on bark surfaces in thin barked areas (fig. 27–4). Pycnidia exude milky masses of conidia. Conidia are

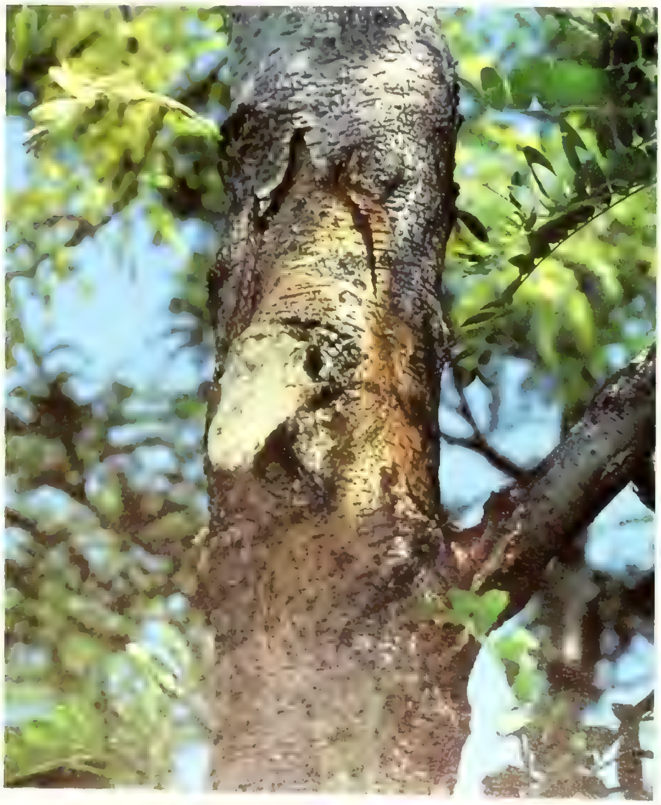


Figure 27-1. Thyronectria canker on a honeylocust originating from a branch stub.

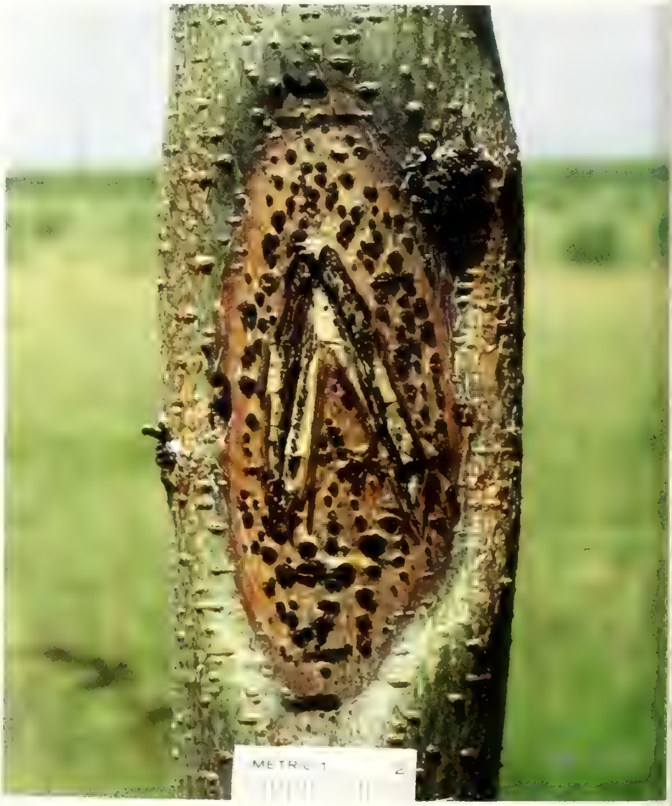


Figure 27-2. Canker on an inoculated honeylocust with large, dar colored masses of pycnidia extruding through bark.

yaline, ovoid to ellipsoid, one-celled, and are 1.6–4.2 y 0.8–2.7 μm in size. The perithecia develop in rounded lusters in a stroma, and are smooth-surfaced and egg-haped with a short neck. Asci contain 8 ellipsoid to ear-shaped ascospores. The hyaline to pale yellow scospores have both transverse and longitudinal septa nd range in size from 8–16 by 5–9 μm.

Nectria canker of honeylocust induced by *Nectria cin-abarina* appears very similar to Thyronectria canker, nd is best distinguished from *T. austro-americana* on ultural characteristics, morphology of the asexual ruiting structures, and ascospore morphology. *T. austro-mericana* cultures have somewhat waxy margins with range slimy centers containing masses of conidia. *N. innabarina* cultures are white and fluffy. *N. cinnabarina* nduces cankers that are usually sunken and contain a porodochial asexual stage (*Tubercularia vulgaris*). The scospores of *N. cinnabarina* are divided into two cells y a single transverse septum, unlike those of *T. austro-mericana*.

isease Cycle

The *Thyronectria* fungus overwinters as mycelium and ruiting structures on infected trees. Conidia presumably re spread by rain and ascospores by wind, although this as not been demonstrated. Infections are thought to take lace through pruning wounds and other natural open-gs. Fresh bark wounds are infected readily by the ungus. Because the fungus is also a saprophyte, it can ecome established on dead wood such as branch stubs r wound edges.

The fungus grows in the cambium and outer xylem, here it eventually kills the cambium and surrounding ells. Trees, or affected parts, die because of cambial eath and possible vascular dysfunction. Pycnidia can rm within one month after tissue is colonized, and are bundant on bark of dying or dead trees. Perithecia form affected areas but are not as common or abundant as ycnidia. Spore release is favored by high humidity and in; spore germination is optimum at 77°–86°F. Infec-on and disease development is rapid at temperatures 75°to 82°F.

amage

Cankers at the tree base are usually fatal. Main stem branch crotch cankers may cause complete girdling, pending on the tree's health. Stressed trees cannot mpartmentalize the fungus, whereas vigorous trees ay be able to callus over a canker and recover.

The incidence of the disease across the United States not known, but occurs on honeylocust in urban, rural, d windbreak plantings.

ntrol

Thyronectria canker should be prevented rather than ntrolled. Physical damage and wounds should be oided or properly cleaned and allowed to dry. The gus infects trees under a variety of stresses. Avoid stress due to drought, overwatering, restricted area for root growth, or restricted oxygen for root growth. Trees should be watered adequately but not excessively. Frequent light watering in heavy clay soils allows attack by other fungi at the tree base just below groundline. *T. austro-americana* then infects the weakened tree above the area previously infected by other fungi. Allowing the soil to dry out at the tree base would prevent infections at the soil line.

Pruning infected branches can reduce the chances of other infections. Trees should be pruned in cool, dry weather when the presence of fungal spores is reduced. Small cankers may be scribed out if the tree is reasonably vigorous.

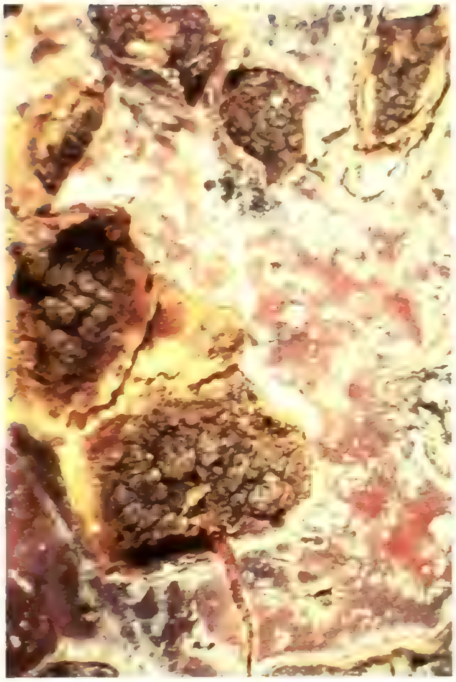


Figure 27-3. Clumps of pycnidia on honeylocust bark (left).

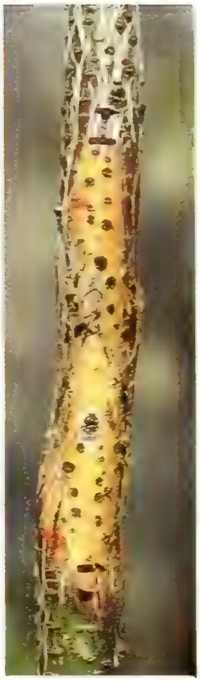


Figure 27-4. Clumps of pycnidia are scattered on stems with thin bark (right).

Selected References

Crowe, F.; Starkey, D.; Lengkeek, V. Honeylocust canker in Kansas caused by *Thyronectria austro-americana*. Plant Disease. 66: 155–158; 1982.

Hudler, George W.; Oshima, Nagayoshi. The occurrence and distribution of *Thyronectria austro-americana* on honeylocust in Colorado. Plant Disease Reporter. 60: 920–922; 1976.

Lieneman, Catharine. Observations on *Thyronectria denigrata*. Mycologia. 30: 494–511; 1938.

Riffle, Jerry W.; Peterson, Glenn W. Thyronectria canker of honeylocust: Influence of temperature and wound age on disease development. Phytopathology. 76: (3): 313–316; 1986.

Seeler, E. V., Jr. Two diseases of *Gleditsia* caused by species of *Thyronectria*. Journal Arnold Arboretum, Harvard University 21: 405–427; 1940.

28. Stem Decays of Willow

James A. Walla and Robert W. Stack

Several species of fungi are able to decay live or dead willow wood. The most common decay fungi on willow in the Great Plains are species of *Daedalea* and *Trametes*. Names used in this text follow Overholts. *Daedalea* and *Trametes* are in the family Polyporaceae. Taxonomic relationships in this family are in a state of revision. Species of *Daedalea* and *Trametes* discussed here have been placed in eight genera (*Antrodia, Cerrena, Coriolus, Daedalea, Daedaleopsis, Datronia, Funalia,* and *Trametes*). Names presently advocated by the U.S. Forest Service Center for Forest Mycology Research are listed in the index next to names used in this text.

Hosts and Distribution

Three species of *Daedalea* (*D. ambigua, D. confragosa, D. unicolor*) and seven of *Trametes* (*T. hispida, T. malicola, T. mollis, T. rigida, T. sepium, T. suaveolens, T. trogii*) that decay willow have been reported in the Great Plains. *T. suaveolens*, which causes a white-mottled heart rot, is the most common decay fungus that attacks live willows. The other species generally are found on dead wood. These fungi are widespread in the Great Plains and have been found on many willow species. Species that decay willow also decay many other hardwoods and some conifers. No decay resistant willow species are known.

Symptoms and Signs

Often the first outward indication of stem decay is formation of fruiting bodies (sporocarps) on the outside of the stem. This fruiting occurs after the fungus has been present for some time and has caused significant decay. Sporocarps of these fungi are usually annual, but they often grow on the same wood for several years.

Sporocarps vary in appearance, both within and among species and genera. Both *Daedalea* and *Trametes* usually have shelflike sporocarps (fig. 28–1), but some may also be appressed on the stem. The lower surface consists of a layer of pores in which spores are produced. In *Daedalea* species, pore openings usually are mazelike (fig. 28–2), but they may vary from round to almost gill-like. In *Trametes* species, the pores have circular to angular openings. Sporocarps of *Trametes* species often are effused-reflexed and spread out over the surface of the host, but turned up at the upper margin to form a pileus (fig. 28–3). Such sporocarps often have toothlike pores. Laboratory diagnosis is required for specific identification.

The fungus can be found before sporocarps appear by cutting or boring into the stem and looking for rotted wood. At this stage, infected wood must be cultured on agar medium to isolate [illegible] for identification.

Daedalea species on willow cause white rot of wooc Most *Trametes* species on willow cause white rot, bu two cause brown rot. Most species of these genera deca sapwood, but at least one causes heart rot. Some whit rot species cause black lines (zone lines) to form in rotted wood. One, *T. suaveolens*, has a characteristic anis (licorice) odor when fresh.

Live trees with internal rot often exhibit top diebac or poor vigor. If trees with these symptoms are examined, the sporocarps of decay fungi may be found on th lower stem.

Some of these species do not attack live trees, and al can grow as saprobes; their presence on dead wood doe not mean they cause tree mortality.

Disease Cycle

The sequence of events leading to decay of living tree by some fungi is as follows: Openings in the bar

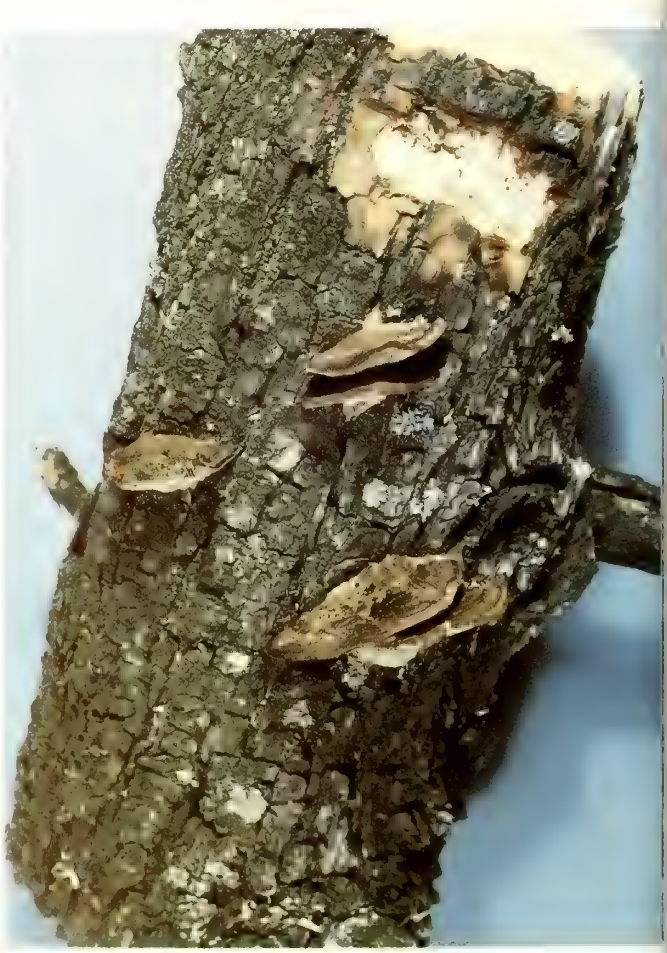


Figure 28-1. Pileus of *Daedalea confragosa*, showing shelflik growth of sporocarps.

wounds, branch stubs) allow nondecay organisms (bacteria, nondecay fungi) to enter the wood. These organisms alter the wood and allow decay fungi to invade and decay the altered wood. Only the wood present at the time of wounding is susceptible to decay. After growth and subsequent wood decay, the decay fungi produce sporocarps to complete their life cycle. The sequence of events has not been examined in decay of willow.

Damage

Young trees are usually free from decay. Incidence of decay increases with advancing age of trees. Decay fungi are common on dead wood. On live trees, decayed stems are more vulnerable to wind or snow breakage. Live trees are seldom killed by decay fungi, but affected wood is unsuitable for use as wood products.

Control

Little can be done to control stem decays after trees are infected; control measures should be directed toward preventing infection. Wounds close faster, and more effective defense barriers are formed on vigorous trees. Maintain tree vigor by applying water and fertilizer if possible. Prevent mechanical wounds and avoid wounds caused by fires. If wounds occur, prune to promote callusing. If branches break, prune back to the nearest living lateral. If a main stem is wounded, shape the wound into an ellipse to promote closing by callus formation.

If thinning is feasible, remove the least vigorous trees and trees that are already or most likely to become infected. Do not damage residual trees while thinning. Remove dead wood from the site.

Selected References

Hepting, George H. Diseases of forest and shade trees of the United States. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture; 1971. 658 p.

Hirt, Ray R. On the biology of *Trametes suaveolens* (L.) Fries. Tech. Pub. 37. Syracuse: Bulletin of the New York State College of Forestry at Syracuse University; 1932. 36 p.

Overholts, Lee Oras. The Polyporaceae of the United States, Alaska, and Canada. Ann Arbor: University of Michigan Press; 1953. 466 p.

Shigo, Alex L. Tree decay: an expanded concept. Agric. Info. Bull. 419. Washington, DC: U.S. Department of Agriculture, Forest Service; 1979. 73 p.

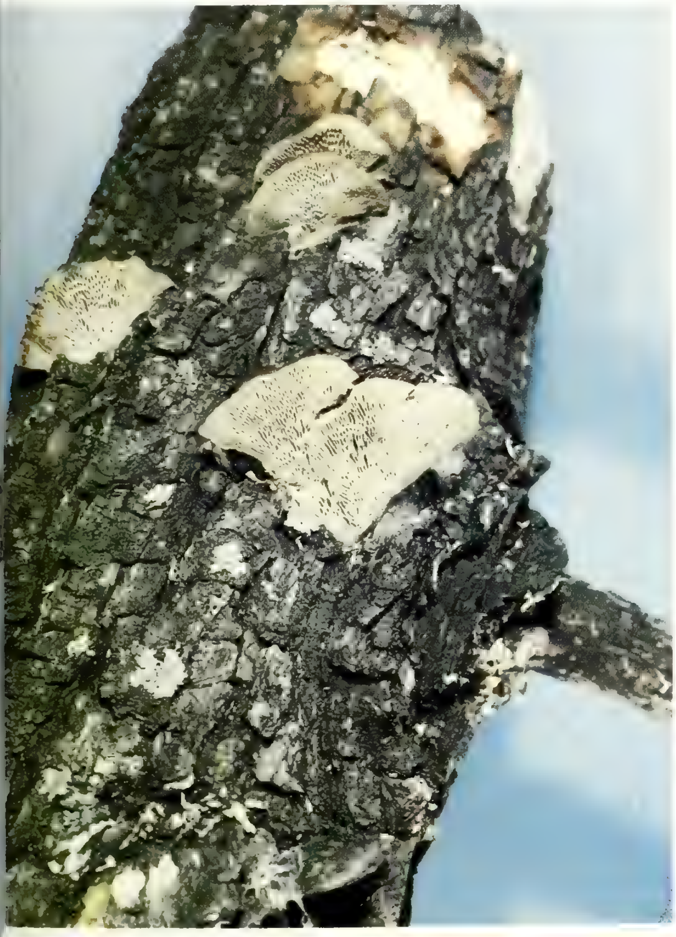


Figure 28-2. Hymenia of *D. confragosa*, showing daedaloid (mazelike) pores.

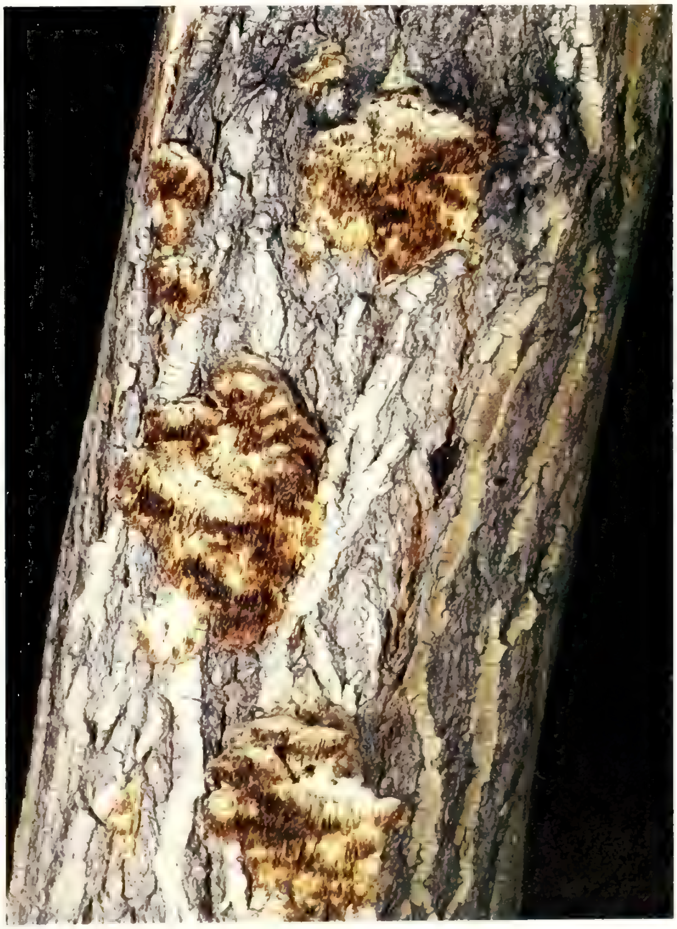


Figure 28-3. Effused-reflexed fruiting bodies of *Trametes trogii* with toothlike pores.

29. Wetwood (Slime Flux) of Elm, Cottonwood, and Mulberry

David W. Johnson and Jerry W. Riffle

Bacterial wetwood is a common disease affecting the xylem of many softwood and hardwood trees. In some species wetwood is lethal, while in others little damage occurs.

Hosts and Distribution

Wetwood affects trees throughout the United States. It is common in elm, mulberry, and cottonwood in the Great Plains. Trees growing on wet sites and poorly drained soils are more likely to develop wetwood than those on upland sites or on well-drained soils. Wetwood has been reported in 86 percent of cottonwood over 6 inches in diameter sampled along the Mississippi River.

Symptoms and Signs

Wetwood can be found in the trunk, branches, and roots (figs. 29–1, 29–2), and has a dark color, high moisture content, elevated pH, decreased electrical resistance, abnormally high gas pressure, and an increase in mobile cations.

Western cottonwoods are often infected early in their life. Dark streaks or bands may appear in the annual rings. Discoloration is most extensive in heartwood or older sapwood, but can occur in current wood. Foliage of affected limbs is often prematurely yellow, scorched, and wilted. Wilting may cause dieback of scattered branches; the entire crown may decline over several years. Premature defoliation may occur, but causes little growth loss.

"Bleeding" or slime-fluxing from trunk wounds, cracks, or other injuries is the most conspicuous symptom. Air-borne bacteria, yeasts, and other fungi contaminate the sap, resulting in a frothy, slimy, foul-smelling liquid, and upon drying it leaves a light gray to white crust (figs. 29–1, 29–2).

Abundant gas is produced in wetwood-affected tissues by the fermenting action of bacteria on carbohydrates and other materials in the sap. The gas is composed primarily of methane, nitrogen, carbon dioxide, and oxygen. When the gas is confined in the trunk, abnormally high pressures of up to 60 psi develop; 5 to 10 psi are common. The accumulation of liquid under pressure results in a water-soaked condition that gives rise to the name "wetwood." The pressure forces the accumulated liquid and gas out of the trunk through cracks in crotches, through pruning and other wounds, and through other natural openings. This liquid can cause localized cambial mortality and prevent callus formation.

Foliage wilts when sufficient quantities of the toxic liquid accumulated in the trunk wood are carried into the branches. Leaves first curl upward along their margins, then the petioles become flaccid, and finally the leaves droop and wilt.

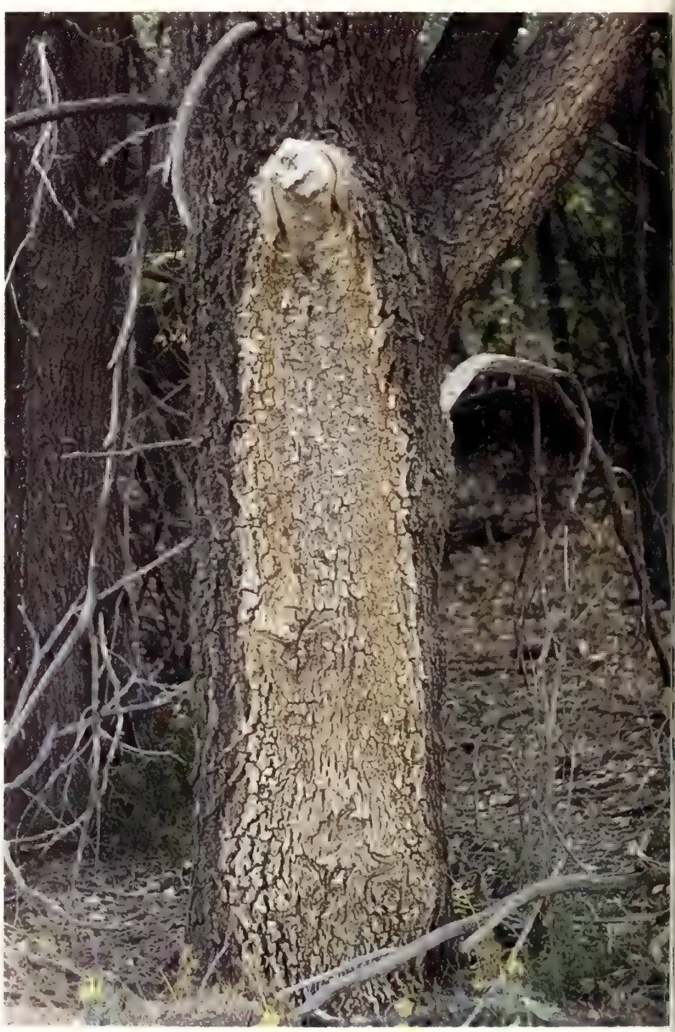


Figure 29-1. Light gray discoloration of bark on Siberian elm affected [illegible] wetwood.

isease Cycle

The bacteria associated with wetwood disease are comnon soil and water inhabitants. Wetwood is primarily ssociated with the facultatively anaerobic bacterium *nterobacter cloacae* (=*Erwinia nimipressuralis*). The acterium is a small, motile, rod-shaped, single-celled, ram-negative organism with up to six peritrichous lagella. Several other bacteria, including species of *Xanhomonas*, *Agrobacterium*, *Bacillus*, *Clostridia*, *cinetobacter*, and *Pseudomonas*, are commonly isolated rom diseased tissue and probably play a role in the proluction of the complex symptoms associated with vetwood.

Roots may become infected through wounds. Bleeding rees harbor large populations of bacteria that may be ransmitted by bark beetles to infect other stem or branch vounds.

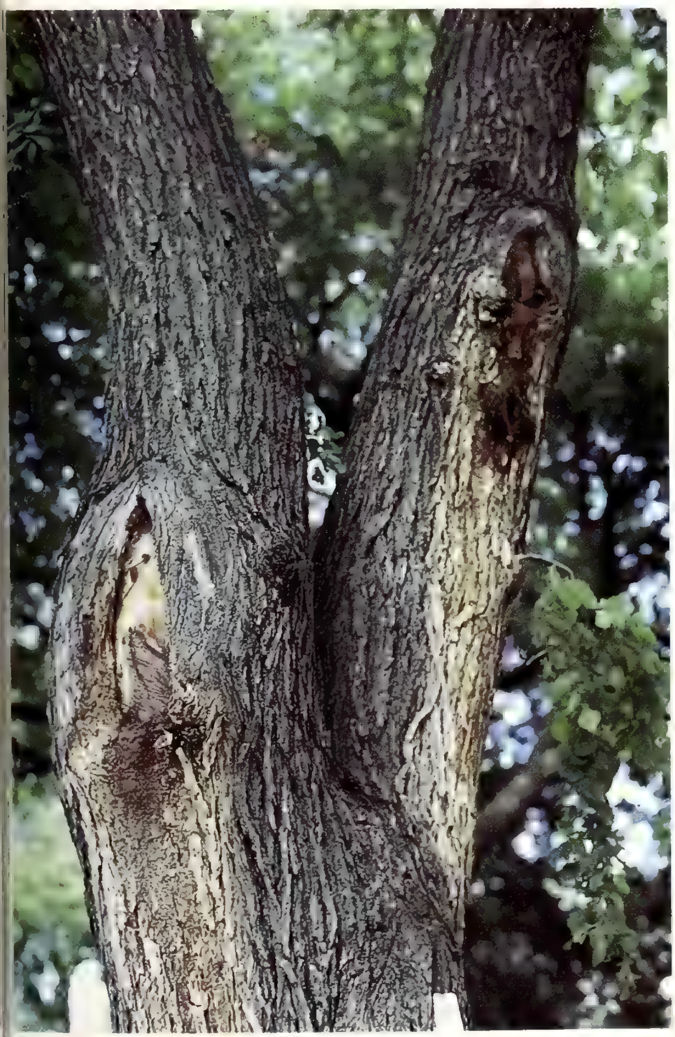


Figure 29-2. Light ash gray discoloration of bark of American elm affected with wetwood.

Damage

Wetwood is a chronic disease that may contribute to general decline, especially of old trees and trees of low vigor. It causes an unsightly and often foul-smelling bleeding from tree wounds. It retards or prevents callus formation over wounds, and therefore lengthens susceptibility to decay fungi. Dripping wetwood flux may kill turf beneath infected trees.

Wetwood is responsible for substantial losses of wood in the forest products industry. Loss occurs through shake and frost cracks in living trees, checking and collapse in lumber and veneer during drying, and increased drying time in the kiln. The stained wood is also a serious defect in lumber and veneer graded on appearance. Strength properties of wetwood-infected tissues do not differ significantly from those of healthy tissues. In fact, wetwood tissue in living trees is rarely decayed, and appears to be resistant to wood-inhabiting fungi.

Control

No completely satisfactory chemical control measures are available. Installation of metal or plastic drain tubes to lower stem pressures and remove excess liquid has prevented additional damage and spread in infected trees, but may allow entrance of decay fungi. Fertilization of affected trees may be helpful in lessening the effects of the disease. Severely affected trees and limbs should be removed in the spring. Care should be taken to sterilize tools after each cut to prevent spread from diseased to healthy trees.

Selected References

Hamilton, W. Douglas. Wetwood and slime flux in landscape trees. Journal of Arboriculture. 6(9): 247–249; 1980.

Hartley, Carl; Davidson, Ross W.; Crandall, Bowen S. Wetwood, bacteria, and increased pH in trees. Report 2215. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1961. 35 p.

Murdoch, Christopher W.; Campana, Richard J. Bacterial wetwood. In: Stipes, R. Jay; Campana, Richard J., eds. Compendium of elm diseases. St. Paul, MN: The American Phytopathological Society; 1981: 31–34.

Murdoch, C. W.; Campana, R. J. Bacterial species associated with wetwood of elms. Phytopathology. 73: 1270–1273; 1983.

Murdoch, C. W.; Biermann, C. J.; Campana, R. J. Pressure and composition of intrastem gases produced in wetwood of American elm. Plant Disease. 67: 74–76; 1983.

Toole, E. Richard. Wetwood in cottonwood. Plant Disease Reporter. 52: 822–823; 1968.

30. Crown Gall of Cottonwood, Willow, and *Prunus* Species

Michael W. Ferguson and Richard Dorset

Species of cottonwood, willow, and *Prunus* are commonly used in windbreak plantings in the Great Plains Region. Many of these species are susceptible to crown gall disease caused by the bacterium *Agrobacterium tumefaciens.*

Hosts and Distribution

Crown gall occurs worldwide on numerous tree hosts, including both broadleaf and conifer species. De Cleene and De Ley (1976) list 643 host plants belonging to 331 genera and 93 families. Most members of the genera *Populus, Salix,* and *Prunus* are listed as susceptible to infection by at least one isolate of *A. tumefaciens.* Exceptions are *Populus canadensis* cv. *serotina erecta, P. robusta, Prunus caroliniana, Prunus divaricata,* and *Prunus ilicifolia,* which appear resistant. While not all of these species may be adapted to the Great Plains region, they could be considered as sources of resistance, providing that their resistance is tested with local isolates of *A. tumefaciens* from the same host genus.

Certain species of *Juniperus, Cupressus,* and *Libocedrus* have been reported as susceptible to the crown gall bacterium. Crown gall occurs on eastern redcedar seedlings in some Great Plains nurseries.

Symptoms and Signs

Individual swellings or galls may form on the aerial portions of the tree (fig. 30–1), or on roots (figs. 30–2, 30–3, 30–4). The galls usually are rounded with rough, irregular surfaces that darken with age. Galls vary in diameter from less than 1 inch to more than 1 foot.

Internally, the galls show irregular structure, with the various tissue elements being disrupted.

Several insects and mites, and physiological responses to grafting or wound regrowth may cause similar-looking galls. The particular diagnostic characters of crown gall are the rough, irregular surface and the lack of small holes (caused by insects) in the core of the gall itself.

The bacterium can be identified by techniques outlined by Schaad (1980).

Disease Cycle

A. tumefaciens is found in the soil, and apparently enters the plant through wounds resulting from cultivation, root pruning, or insect feeding. The bacterium may also be spread through use of contaminated pruning or grafting equipment. After entering the plant, a portion of the bacterial genetic material is transferred to the host resulting in abnormal cell growth and cell numbers in that region of the host tissue. The resultant swollen tissue forms the gall. Young trees, such as nursery stock, may be stunted when the woody tissue is disrupted, preventing flow of water or nutrients. The bacteria re-enter the soil, probably through disintegration of the gall.

Chewing insects can carry the bacteria from plant to plant, while long-distance movement is by infected nursery stock.

Symptoms may not appear for several weeks after infection, depending on weather conditions. Warm weather favors this disease. The bacteria may survive for two years in soil without a host, but may survive longer in decaying galls. Crown gall is favored by soils of neutral or higher pH.

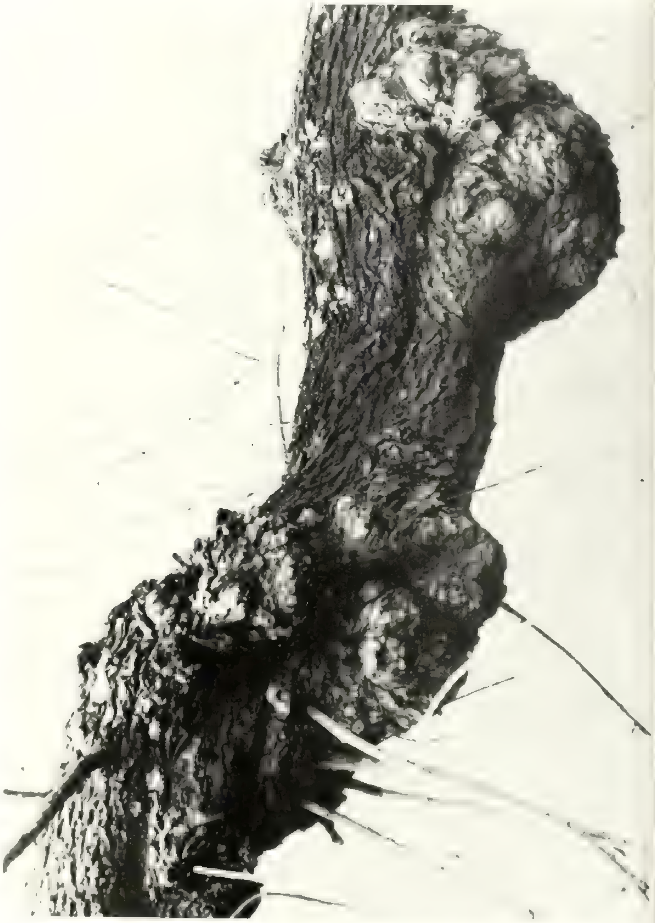


Figure 30-1. Weeping willow with aerial crown galls.

Damage

Infection of large trees is infrequent and results in no economic loss. Infection of nursery stock, however, can be quite extensive, especially when inoculation takes place during propagation. Small trees may be stunted. Normally, in most states there is no tolerance for nursery stock infected with crown gall; all infected plants are destroyed. Subsequent monitoring losses may be high.

Control – In nurseries:

1. Select planting wood or propagation stock from wood free of crown gall.
2. Use care during propagation to avoid transmitting the bacteria from diseased to healthy wood.
3. Sterilize cutting instruments frequently using a disinfectant such as 70 percent alcohol.
4. In species that are vegetatively propagated, use a budding technique rather than grafting.
5. Avoid mechanical wounds of young trees or bushes.
6. Remove and destroy all infected plants.
7. Plant where a non-susceptible crop has been grown for at least 2 years. Growing oats, corn, or a grass crop prior to susceptible crops will reduce crown gall.

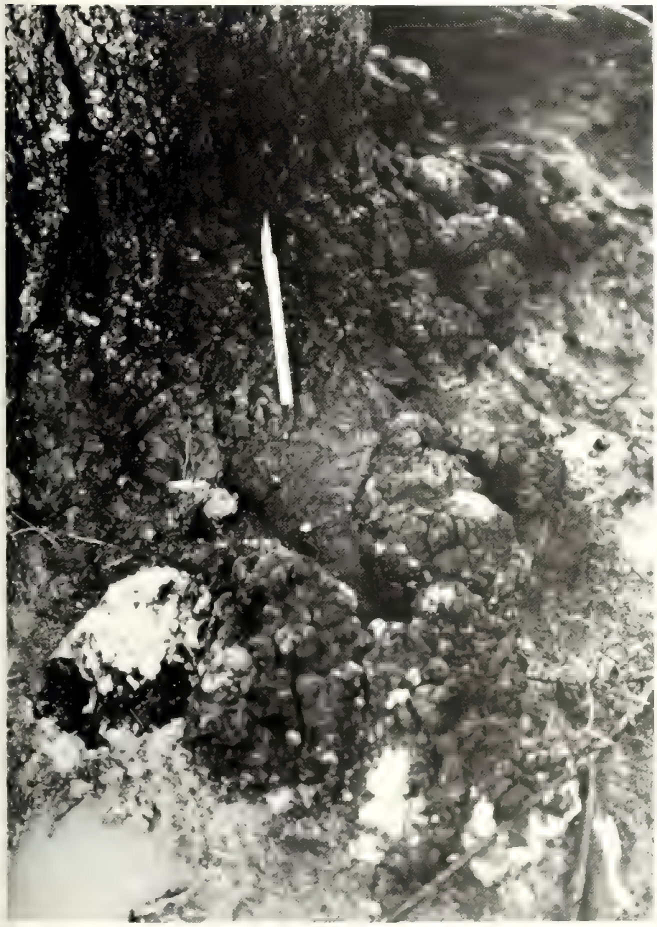
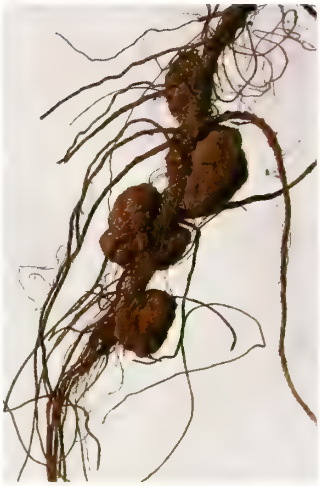


Figure 30-2. Galls on surface of roots of eastern cottonwood.



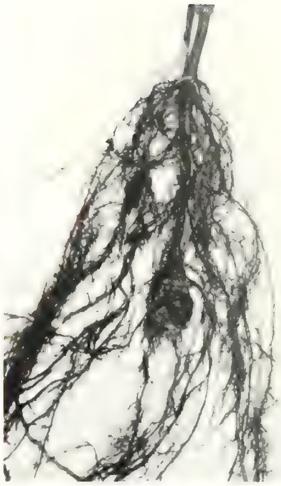


Figure 30-3. Galls formed on roots of pecan (left).

Figure 30-4. Galls on roots of eastern redcedar nursery stock develop at wound where roots were pruned (right).

Control – In general:

1. Infested soil can be treated either with heat (180°F for 30 min) or by soil fumigation (such as methyl bromide or other fumigants). Exposure to moist heat at 150°F for 30 minutes will destroy many plant pathogens, insects, and weeds.
2. Dipping understocks in disinfectants or antibiotics (such as terramycin) can be effective.
3. A biological control has been shown to be effective utilizing a related bacterial species *A. radiobacter* (Strain 84), which is antagonistic to *A. tumefaciens*. Nursery stock is dipped in a solution of live bacteria before planting. The antagonistic bacteria produce a toxin that prevents infection by *A. tumefaciens*. This treatment should be effective in large plantings such as nurseries if crown gall is a chronic problem.
4. The best control is to plant disease-free stock.

Selected References

Anderson, A. R.; Moore, L. W. Host specificity in the genus *Agrobacterium*. Phytopathology. 69: 320–323; 1979.

De Cleene, Marcel; De Ley, Jozef. The host range of crown gall. The Botanical Review. 42: 389–466; 1976.

Schaad, Norman W. Laboratory guide for the identification of plant pathogenic bacteria. St. Paul, MN: American Phytopathological Society; 1980. 72 p.

Smith, Clayton O. Susceptibility of species of Cupressaceae to crown gall as determined by artificial inoculation. Journal of Agricultural Research. 59: 919–925; 1939.

Spiers, A. G. Biological control of *Agrobacterium* species on *Salix*. New Zealand Journal of Agricultural Research. 23: 139–142; 1980.

31. Hypoxylon Canker of Oaks

Kenneth E. Conway and Mark W. Andrews

Oaks (*Quercus* spp.) are important in the southern and eastern Great Plains as shade and forest trees. Hypoxylon canker caused by the fungus *Hypoxylon atropunctatum* has become an increasingly important stress-related disease on oaks.

Hosts and Distribution

H. atropunctatum infects most species of oak and has been reported on maple, beech, basswood, and sycamore. Outbreaks of this disease following drought have been reported from Oklahoma, Arkansas, Mississippi, and Florida. In Oklahoma, the disease has been diagnosed from several habitats including forest sites, trees in pastures, recently developed home sites, and established residential areas.

Symptoms and Signs

The most obvious symptom of Hypoxylon canker is the sloughing of bark to expose an effuse silver stroma or cushion of the fungus (fig. 31–1). Information on how this organism attacks and kills trees is limited. It is known that trees that have been stressed or weakened by drought or have had their root systems injured are much more susceptible than healthy trees.

Disease Cycle

The fungus evidently enters branches through wounds, grows through the sapwood, and causes decay. The first symptoms are yellowing and wilting of leaves, and death of top branches of the tree. The fungus is capable of

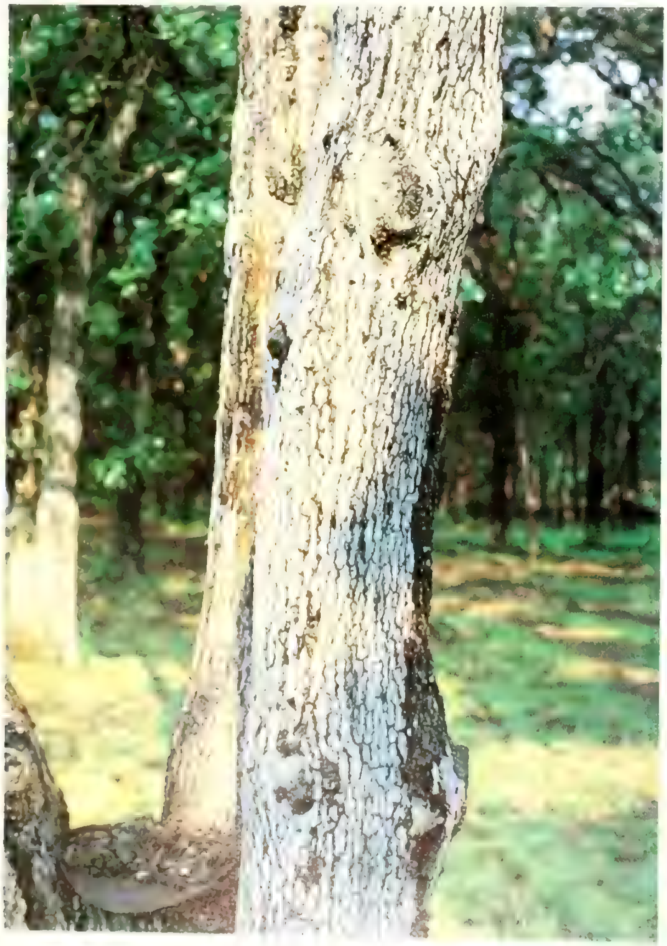


Figure 31-1. *Hypoxylon* [illegible] on oak showing the effuse [illegible]

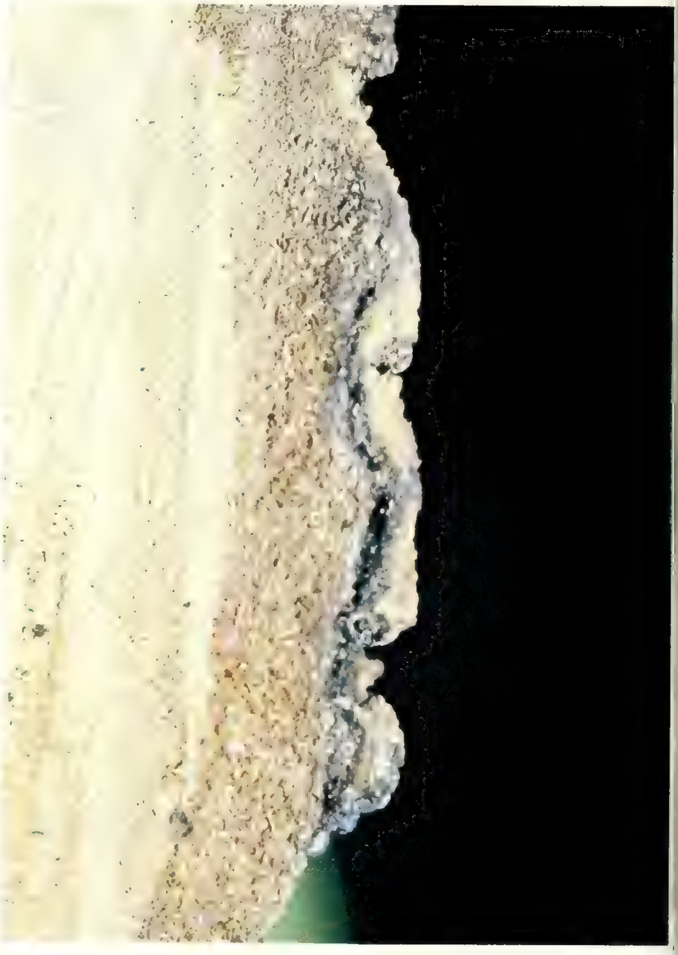


Figure 31-2. Cross section of an infected oak log showing canker formation within the bark.

spreading 3 feet above and below the point of inoculaion within one growing season. The fungus may be acive in trees for a number of years before symptoms are oticed. It may kill trees that are weakened or injured.

The disease develops through branches, causing progressive dieback. Later, the outer bark is sloughed fig. 31–2), exposing a thin stroma. Initially the stroma ears brownish, dusty masses of one-celled conidia, which are easily blown from tree to tree and cause new nfections (fig. 31–3). The stroma quickly changes to silver and later to black, and becomes thicker and harder s the sexual stage of the fungus develops (fig. 31–4). Inside the stroma, the sexual stage produces fruiting bodies perithecia) in which masses of dark spores are formed. Spores ooze out of the perithecia onto the surface of the stroma, where they can be spread by various means (rain, nsects) to other branches or trees. Large trees may be killed within 1 or 2 years, depending on the health of he tree. Because initial stages of the disease may go unoticed, however, trees may appear to die within a eriod of a few weeks. Stromata may be limited in their evelopment, or extend the length of the tree.

Damage

Reports from Arkansas and Oklahoma indicate that the red and black oaks are more susceptible to Hypoxylon canker than are the white oaks. Canker formation is also more effuse on red and black oaks. Cankers were found on 65–95 percent of the dead oaks observed in two surveys in Arkansas. Measured and potential losses of gross volume of red oak in Arkansas were estimated at 7.1 percent of total volume.

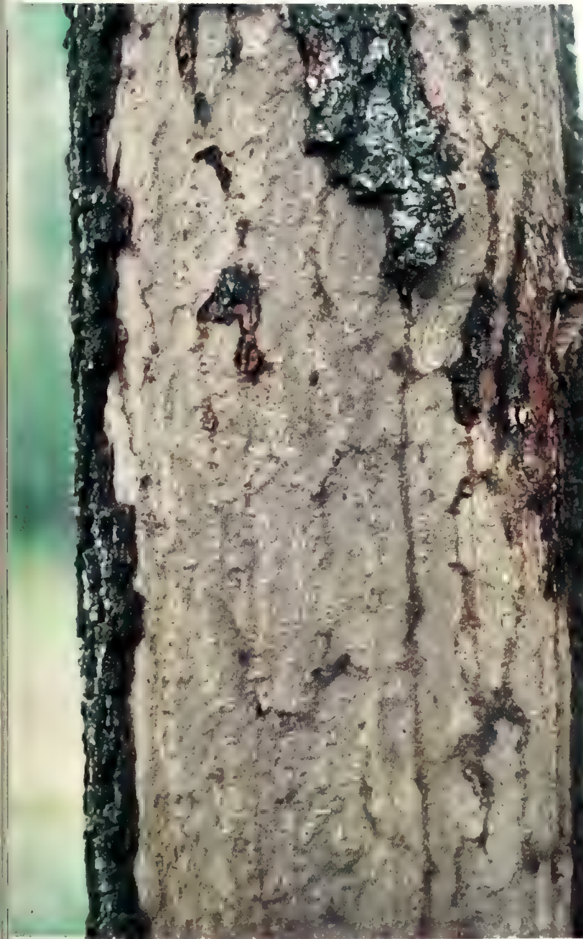


Figure 31-3. Young dusty brown colored canker composed of conidia of the asexual stage.

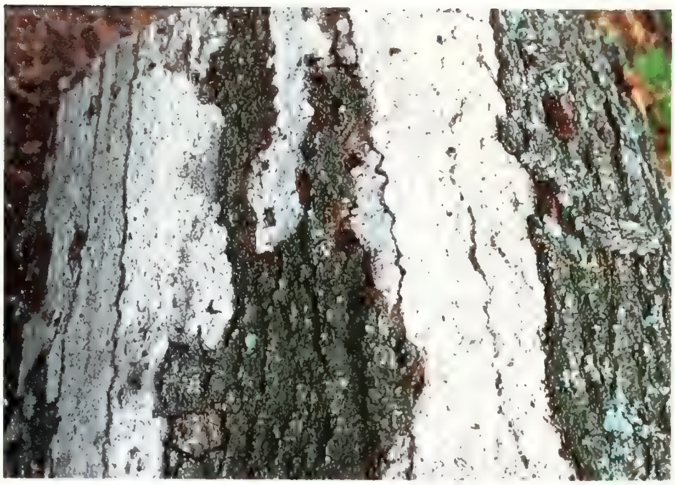


Figure 31-4. Close up of an older stroma of *H. atropunctatum* on an oak stump.

Control

There is no effective control for this disease. In commercial operations where trees can be harvested for pulp, trees should be cut before decay reduces their value.

In urban areas, trees with more than 15 percent of the crown area infected should be cut to ground level and burned. No stump should be left because, in several instances in Oklahoma, stroma have developed on stumps with as little as 6 inches exposed above the ground (fig. 31–4). Trees with less damage should be given extra care, such as watering during drought, and fertilization. Because the fungus remains active on dead wood, fuel wood should be burned as soon as possible to prevent further sporulation and spread of this disease. In addition, all dead branches should be pruned from the tree and destroyed. The best defense against this disease is to maintain trees in a healthy, vigorous growing condition.

Selected References

Bassett, Edward N.; Fenn, Patrick; Mead, Margaret M. Drought-related oak mortality and incidence of Hypoxylon canker. Arkansas Farm Research. 31: 8; 1982.

Conway, K. E. Hypoxylon canker of oaks. Extension Facts No. 7620. Stillwater, OK: Oklahoma State University; 1980. 2 p.

Lewis, R., Jr. *Hypoxylon* spp., *Ganoderma lucidum*, and *Agrilus bilineatus* in association with drought related oak mortality in the South. (Abstract) Phytopathology. 71: 890; 1981.

32. Black Knot of Cherry and Plum

David S. Wysong and Mark O. Harrell

Increased interest in prune and plum production in the Midwest has made black knot, caused by the fungus *Apiosporina morbosa* (= *Dibotryon morbosum*), of concern to commercial fruit growers.

Hosts and Distribution

The two major plum varieties grown in the Midwest, Stanley and Damson, are susceptible to the black knot pathogen. Bluefire is also susceptible. Varietal susceptibility tests in Pennsylvania show Shropshire to be highly susceptible also. Methley, Milton, Early Italian, Brodshaw, and Fellenburg were moderately susceptible; Shiro, Santa Rosa, and Formosa were slightly susceptible in these tests. President is apparently resistant to the black knot fungus. Black knot is severe on wild plum (fig. 32–1) and cherry seedlings (fig. 32–2), but the disease is not known to occur on commercial cherry trees. However, infected wild hosts are important because the fungus can spread from areas containing diseased plants to the commercial or backyard plum planting.

Symptoms and Signs

The disease is characterized by production of elongated swelling or knots on the limbs of susceptible cherry and plum. These corky outgrowths predominate on small twigs and branches and on the trunk. Knots, which are longer than wide, may reach 1 foot or more in length.

Knots are greenish and soft when newly formed, but they become hard and black with age (fig. 32–3). Old knots may be covered with a white or pink parasitic fungus during the summer, and may be infested with insects.

Disease Cycle

In spring, when about 1 inch of new growth is present, spores are initially discharged from fungal fruiting bodies along the surface of the knots. Spore discharge is moderate to heavy from pink blossom stage to 2 weeks after bloom, and ends about the time terminal growth stops. Rain is required for spore discharge. Spores are carried by wind and rain to the site of infection, where

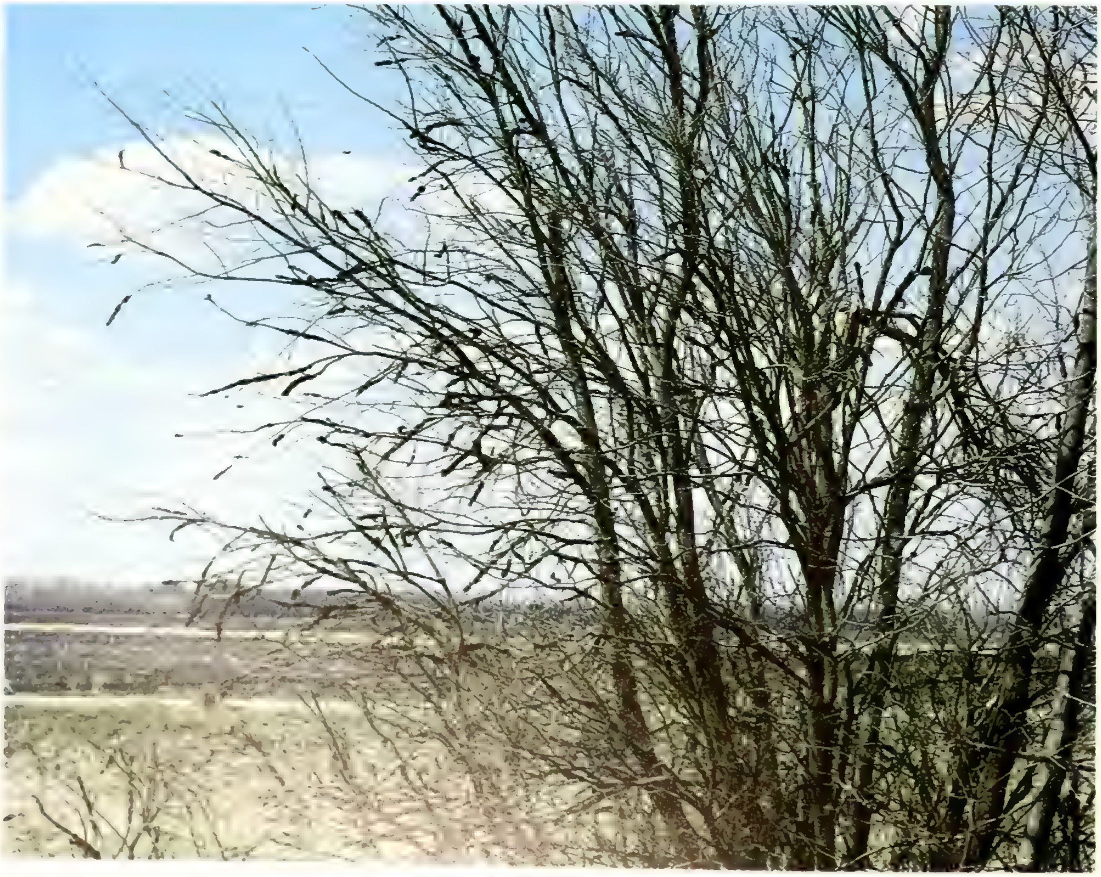


Figure 32-1. Black knot of American plum.

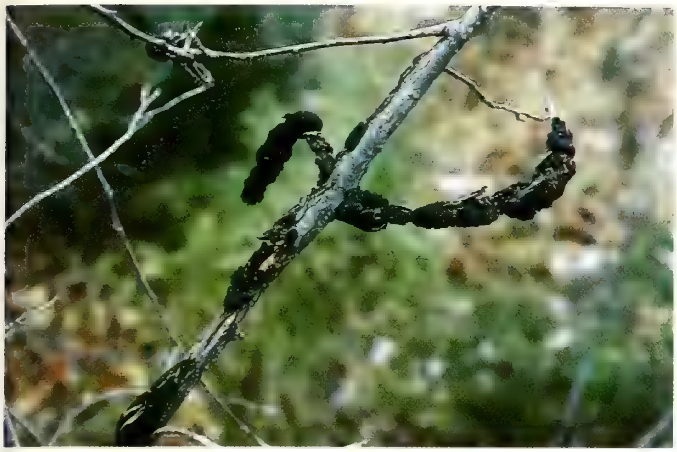


Figure 32-2. Black knot on chokecherry.

they germinate. The fungus penetrates unwounded surface tissue. Infection is most severe when moist conditions are accompanied by temperatures between 55° and 77° F.

Knots appear several months after initial infection. Some knots are visible by late summer; others do not appear until the following spring. At least 1 year, and usually 2, are required before new knots produce mature fruiting bodies. The knots continue to grow during the fall and early spring months, and may reach several inches in length.

Damage

Fruiting capacity of hosts is markedly reduced when the disease is not controlled because extensive pruning is required to remove diseased branches.

Control

Plans to prevent disease build up in new plantings should be developed before the orchard is established. Wild plums and wild seedling cherries should be removed from fence rows and nearby wooded areas. Establish and maintain at least a 600-foot border free of wild hosts. Do not plant new plum trees next to old plantings with black knot. These simple precautions will greatly reduce disease problems and increase orchard longevity. Once established, the plantings and surrounding wooded areas should be inspected annually for black knot. Infections are more difficult to find in mid-August; however, removal of knots at this time is desirable because they are generally fully extended. Cuts should be made 2 to 3 inches below the swelling. Remove knots on the trunk or main branches by cutting away the diseased tissue down to the wood and at least one-half inch outward beyond the margin. When infection is severe, do not remove knots until late winter or early spring so as not to promote excessive vigor. Because the fungus may have extended beyond the swelling, cuts should be made well below the visible infection. Gather and remove the knots from the orchard floor and burn before April 1st since they can be a source of inoculum if left where they fall.

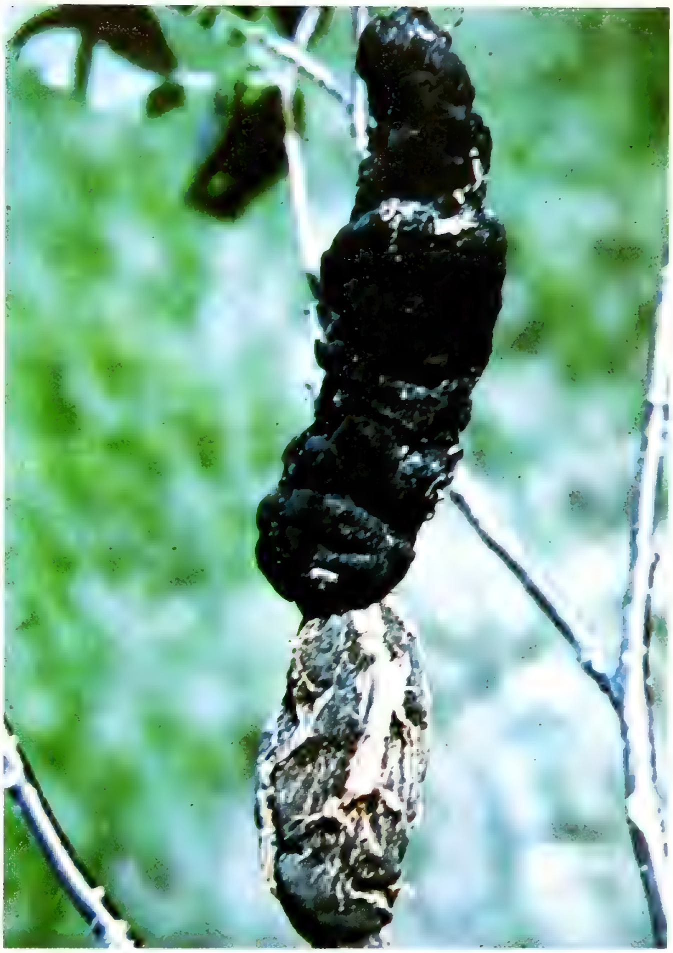


Figure 32-3. Newly formed knots adjacent to old knots.

Sanitation measures usually control the disease adequately, but may be supplemented with a fungicide program if the disease is unusually difficult to control. Spraying, if done in conjunction with a sanitation and pruning program, will help prevent the disease, but spraying alone will not provide satisfactory control. The most effective times to spray are green tip, bloom, petal fall, and shuck fall. Additional sprays, until terminal growth stops, may be necessary under severe conditions. Fungicides registered for use in the control of black knot include:

1. Lime sulfur – One half pint (236 ml) of 30.0 percent solution per gallon of water.
2. Tribasic copper sulfate – One to 1.6 pounds metallic copper equivalent of a wettable powder formulation plus 8 to 12 pounds of hydrated lime suspended in 100 gallons of water.

Selected References

Agrios, George N. Plant pathology, second edition. New York: Academic Press; 1978. 703 p.

Anderson, Harry Warren. Diseases of fruit crops. New York: McGraw-Hill; 1956. 501 p.

Childress, Adele M. Diseases in the home orchard. Ext. Bull. E–1439. East Lansing: Michigan State University; 1981. 8 p.

33. Plum Pockets

William R. Jacobi and John E. Watkins

Plum pockets is a disease of plums caused by *Taphrina communis*. *Taphrina pruni*, another causal agent of plum pockets commonly found in Europe, has been reported on plums in North America, but the report is not confirmed.

Hosts and Distribution

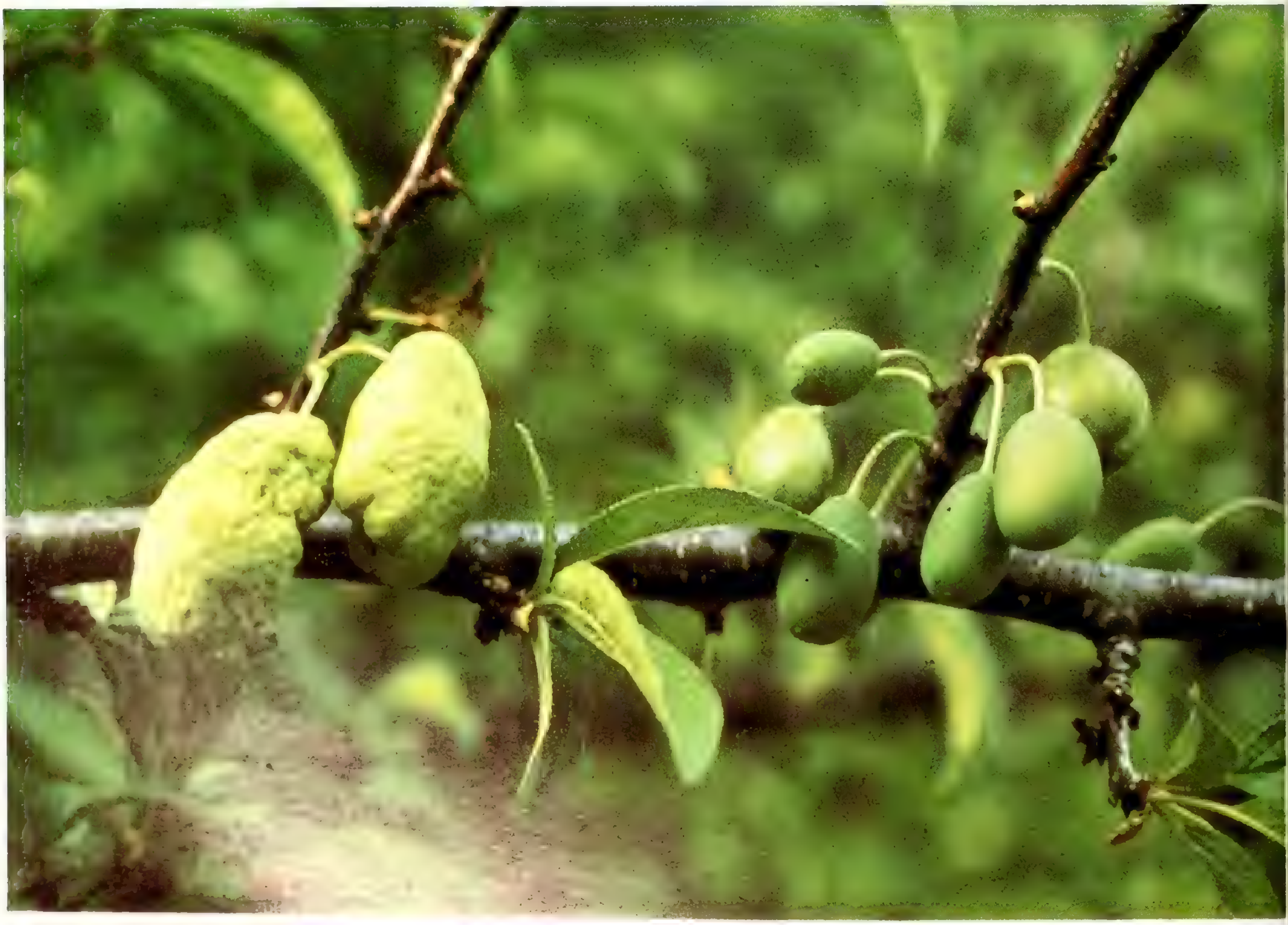
All plum species and varieties are susceptible to *T. communis*. *T. communis* is found in most regions of the United States where plums are grown, but the exact distribution in the Great Plains region is unknown.

Symptoms and Signs

Symptoms appear as small white blisters on the young fruit. The blisters enlarge as the fruit develops and eventually involve the entire fruit. The infected fruit increases in size and becomes spongy and distorted (fig. 33–1). The seed does not develop, and a hollow cavity forms in the infected fruit. The fruit is reddish initially, then becomes covered with greyish powder consisting of asci. Young shoots and leaves also may become infected and malformed (fig. 33–2).

The asci are cylindrical-clavate and usually rounded at the apex. Stalk cells supporting the asci are narrower than the ascus and variable in length. The eight ascospores are round, ovate, or elliptical. The ascospores commonly germinate in the ascus and produce conidia by budding. The dimensions of the asci are 27–83 by 5–18 μm, of the stalk cells 6–56 by 3–12 μm, and of the ascospores 4–7 by 3.5–5.5 μm. One obvious feature that distinguishes this fungus from other *Taphrina* spp. is the long asci that frequently project above other asci.

Figure 33-1. Distorted, enlarged plums affected by plum pockets disease, and healthy unaffected plums.



Disease Cycle

The fungus apparently overwinters as conidia or ascospores on twigs and buds on the tree. In the spring these spores are blown to young, succulent tissues. The spores germinate and penetrate developing leaves or other tissues through stomata or directly through cell walls. The mycelium grows between cells, causing abnormal cell enlargement and division. Infected fruit or tissue is distorted and much larger than normal.

The fungus produces asci below the epidermis of the fruit. These eventually enlarge and break through the epidermis. The ascospores multiply by budding off conidia inside or outside the ascus. Spores are wind blown to new tissue, where infection takes place during bud break. Low temperatures and high humidity favor infection of susceptible tissue. All tissues become resistant as they mature.

Damage

Fifty percent or more of the fruit may be lost in years when the disease is severe. Buds and twigs may be affected, thus stressing the tree. Once the disease is established in a tree, it will appear each year unless controlled.

Control

The disease can be controlled by a single fungicide application in late fall or early spring before leaf buds swell. Any fungicide that is labeled for use on plum trees would be legally acceptable. Fungicides that have been effective are Ferbam, lime-sulfur, and Bordeaux mixture.

Selected References

Agrios, George N. Plant pathology, second edition. New York: Academic Press; 1978. 703 p.

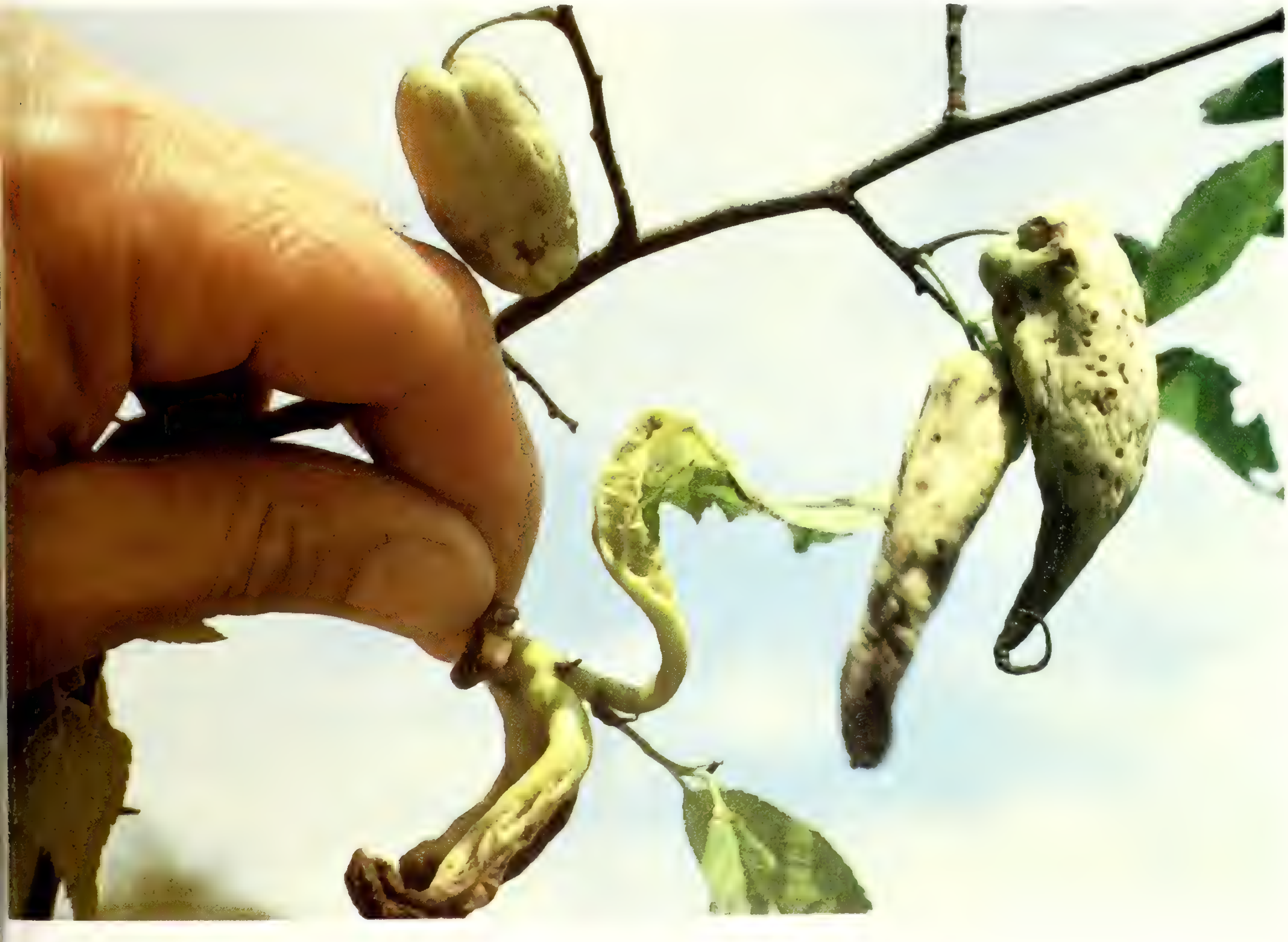
Galloway, B. J. Plum pocket. U.S. Agriculture Comm. Report 1888: 366–369; 1889.

Mix, A. J. A monograph of the genus *Taphrina*. Univ. Kansas Sci. Bull. 33: 3–167; 1949.

Swingle, D. B.; Morris, H. E. Plum pocket and leaf gall on Americana plums. Univ. Montana Agric. Exp. Sta. Bull. 123: 167–188; 1918.

Wilson, E. E.; Ogawa, J. M. Fungal, bacterial, and certain nonparasitic diseases of fruit and nut crops in California. Agriculture Science Publication. Berkeley: University of California; 1979. 190 p.

Figure 33-2. Distorted plums and leaves on plum tree affected by plum pockets disease.



34. Brown Rot of Stone Fruits

David S. Wysong and James A. Walla

A common and destructive disease of stone fruits called brown rot, blossom blight, twig blight, and/or brown rot canker is caused by the fungus *Monilinia fructicola* (*Sclerotina fructicola*).

Hosts and Distribution

All of the commonly cultivated stone fruits, including cherry, apricot, and plum, are susceptible. The disease is less important on apple and pear, and of minor importance on flowering almond, cherry-laurel, chokecherry, flowering quince, and western sand-cherry.

While brown rot is world-wide, it is of little importance in regions where rainfall is low. Severe epidemics are common in the high-rainfall peach-growing areas of the Southeast and along the Atlantic Seaboard, but may also occur elsewhere when moist conditions prevail during fruit ripening.

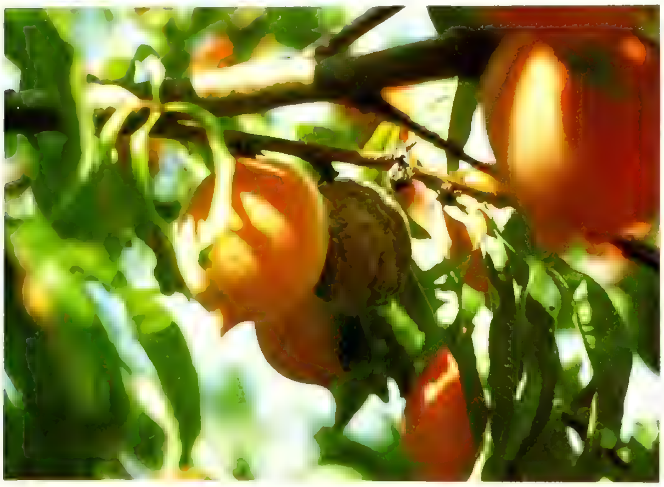
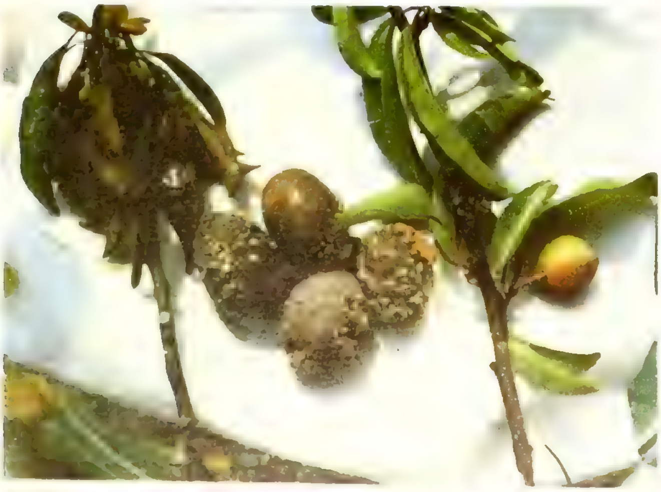


Figure 34-1. Mummified fruit with adjacent non-infected fruit clinging to the branch.

Figure 34-2. Formation of ash-gray mold on surface of infected fruits.



Symptoms and Signs

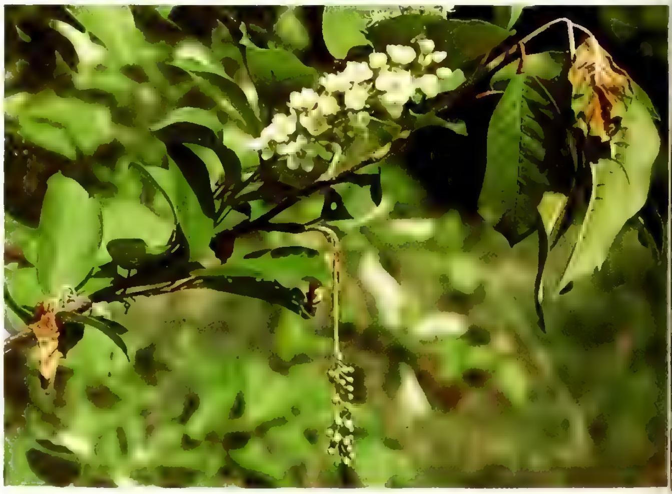
Brown rot is usually first seen as the fruit approaches maturity. Small, circular, light brown areas of decay appear on the surface of the fruit, expand rapidly, and within a few hours may encompass the entire fruit. A day or so later the fruits rot. Some fall to the ground, while others remain attached to the tree, where they dry and become mummified (fig. 34–1). In warm, wet, humid weather, tufts of ash-gray mold develop over the surface of the rotting fruits (fig. 34–2). These fungal masses help distinguish brown rot from other diseases.

Flower blossoms, fruit spurs, woody shoots, and immature fruit are also attacked (fig. 34–3). Infected blossoms wilt, turn brown, and persist into summer. The fungus may progress downward into the flower cluster base and into the fruit spur (fig. 34–4). When the fungus grows into woody tissue, small cankers are formed. They enlarge and may girdle the branch or twig, killing terminal growth. Droplets of resinous gum may accompany the blighted spurs and cankers.

Disease Cycle

The brown rot fungus overwinters in mummified fruits, branch or twig cankers, and infected peduncles. In spring, when fruit buds are opening, small cupshaped apothecia arise from the mummies beneath infected trees (fig. 34–5). When these apothecia are wetted, spores produced within them are ejected into the air and carried by wind to infect blossoms or new shoots.

Figure 34-3. Infected shoot and immature fruit.



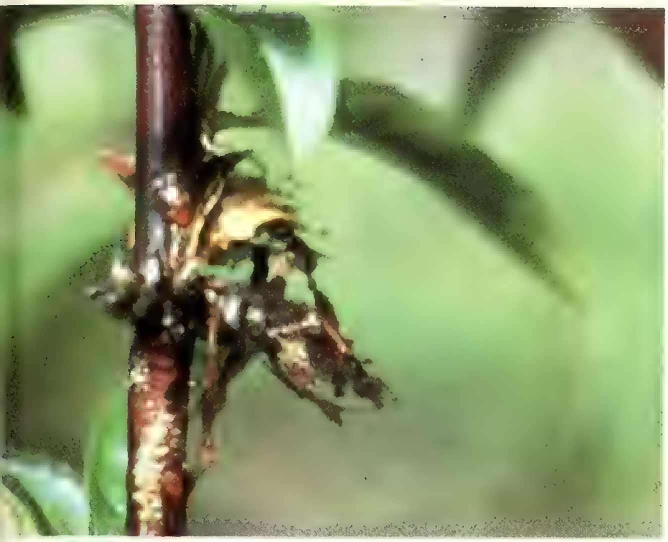
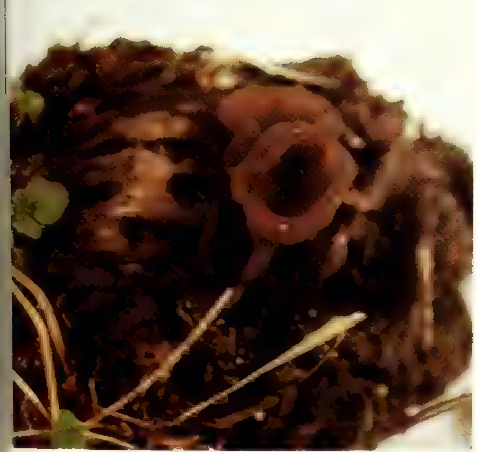


Figure 34-4. Infected flower cluster and fruit spur.

Infection may also arise from a second type of spore produced later in the season on dead blossoms, in spur or twig cankers, or on attached mummies. These spores are also carried by wind or splashing rain to infect ripening green fruit. Infection may occur directly through the cuticle or through natural openings. Wounded fruit is infected much more rapidly than unwounded fruit. Injuries caused by the stink bug, plum curculio, and other insects are frequently avenues of entrance for the brown rot fungus.

Warm, wet, humid weather favors rapid development f brown rot. The time of wetting necessary for blossom infection decreases from 18 hours at 50°F to 5 hours at 7°F. Infection rate decreases above 80°F and below 5°F, but may continue at temperatures as low as 40°F. Under optimum conditions, mature fruit decays in 36 o 48 hours.

Figure 34-5. Close up of infected fruit and developing apothecium.



Damage

Brown rot is economically important in commercial and home orchards. The disease reduces yields by damaging blossoms, twigs, and fruit. After harvest, fruit decomposition poses a constant threat in storage and transit.

Control

Brown rot control involves integrating several disease prevention methods. Control starts with removal of all fruit, mummies, and blighted twigs from trees in the fall. This procedure reduces the amount of brown rot fungus surviving the winter. Cultivate around trees before first bloom to reduce the early spring spore potential. Prune trees to promote good air circulation.

Fungicidal applications at blossom time and pre-harvest time are also important (table 34–1). Blossom blight must be avoided to insure against fruit infection later in the season. The first spray should be applied when the pistil tips extend above the flowers, even unopened flowers. If warm, wet weather prevails, spray every 4 to 5 days until one week after petal drop. Begin pre-harvest sprays about 3 weeks before harvest to control brown rot on ripening fruit. If brown rot has built up, the pre-harvest sprays should be started earlier. Applications should be made at closer than weekly intervals if weather is warm and wet as the fruit colors.

Plant fruit trees in a sunny, open site with well-drained soil away from frost pockets. Plant resistant cultivars when available. Do not plant near wild fruit trees because they may be a source of inoculum. Control fruit injury (e.g. insect or mechanical damage) to prevent early infection of fruit. Apply fungicides if such injury occurs. Excess nitrogen application may increase infection.

Selected References

Byrde, R. J. W.; Willetts, H. J. The brown rot fungi of fruit, their biology and control. New York: Pergamon Press; 1977. 171 p.

Zehr, Eldon I. Control of brown rot in peach orchards. Plant Disease. 66: 1101–1105; 1982.

Table 34–1. Recommended fungicides for brown rot control.

		Minimum number of days from last application until harvest			
Chemical	Rate/gal (3.8 L)	Apricots	Cherries	Peaches	Plums & Prunes
Benomyl, 50% WP (Benlate, Benomyl)	3/4 - 1 1/2 Tbs[1] (5.4 to 10.8 gm)	0	0	0	0
Captan, 50% WP (Captan, Orthocide)	3 1/3 Tbs (28 gm)	0	0	1	0
Sulfur, 80–92% WP (Flotox)	2 1/2 Tbs (19 gm)	—[2]	0	0	0
Ferbam, 76% WP (Fermate)	1 Tbs (6.8 gm)	—	0	21	7

[1] Tbs = tablespoonsful [2] — = not registered

35. Fire Blight of Pear, Apple, Cotoneaster, and Other Ornamental Shrubs and Trees

John E. Watkins and Mark W. Andrews

Fire blight, caused by *Erwinia amylovora*, is the first plant disease shown to be caused by a bacterium. It is apparently indigenous to North America; it was first observed in 1780 in the Hudson River Valley in New York State. It is a major threat to susceptible pear, apple, crabapple, and cotoneaster cultivars.

Hosts and Distribution

Fire blight occurs on most species of Pomoideae and some species in the sub-families of the Rosaceae. Of the genera reported susceptible to fire blight, *Malus* (apple), *Pyrus* (pear), *Cotoneaster* (cotoneaster), *Crataegus* (hawthorn), *Cydonia* (quince), *Pyracantha* (pyracantha), and *Sorbus* (mountain ash), are the most important economically and show the most severe blight. Resistant species and/or cultivars of most hosts are available. Some clonal selections and cultivars of *Pyrus communis* are highly resistant. Nearly all selections of the callery pear (*P. calleryana*), including the Bradford cultivars, show good resistance. Several cultivars of the cultivated species of apple and crabapple are resistant.

Fire blight is native to North America. Since its first observation in New York, it has been found throughout the United States.

Symptoms and Signs

The bacterium infects blossoms and leaves near the growing tips. Leaves quickly wilt and turn black, but remain attached to infected twigs (fig. 35-1). The scorched appearance of affected branches is the most obvious symptom. The affected parts first appear water-soaked, then wilt, shrivel, and turn brownish to black. The bacterium may advance down a small branch to older branches, causing dark, sunken stem cankers (fig. 35-2). Those cankers at ground level are sometimes referred to as collar blight. Infection may spread into the roots, where the bark is killed in a manner similar to that on the trunk. Fruit blight generally is found in immature fruit.

With few exceptions, symptoms on pyracantha, hawthorn, and cotoneaster (fig. 35-3) are generally similar to those on pear, apple, or crabapple.

Disease Cycle

During spring the pathogen begins to multiply. A milky to amber-colored exudate containing millions of bacterial cells oozes from the peduncle, the lenticels in the skin of fruits, and from the margins of cankers (fig. 35-4). This sticky exudate attracts insects that carry the bacteria to blossoms and leaves. The bacteria enter the host through natural openings in blossoms and leaves or throug wounds. Colonization proceeds intercellularly after th primary infection. The bacteria spread through th tissues, and secondary infection may continue throughout the growing season. Bacterial ooze or strands produced on blossoms, shoots, leaves, fruits, or large branches are the sources of secondary inoculum, which can be spread by rain, wind, insects, or birds.

The bacterium overwinters in tissue adjacent to th margins of cankers. The pathogen is more likely to overwinter successfully in cankers with smooth margins an healthy tissue on all sides. The bacteria again multipl in spring and invade healthy tissue. In addition to producing primary inoculum, extending cankers can significantly injure trees.

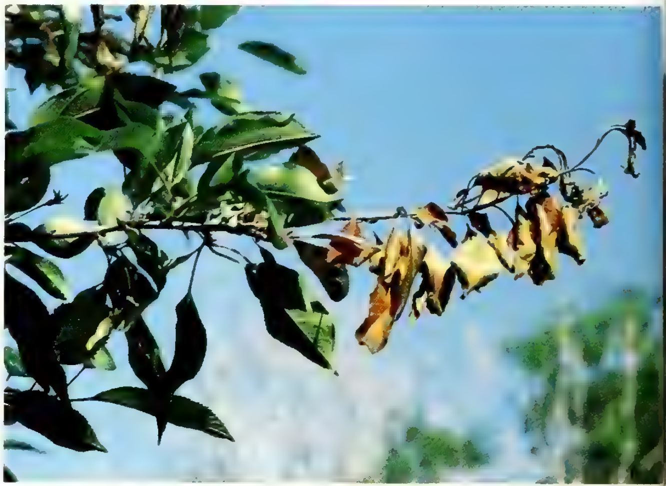
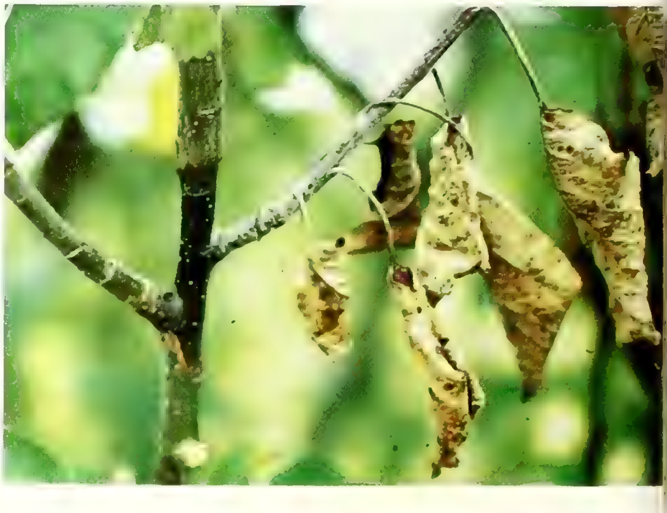


Figure 35-1. Scorched appearance of blighted foliage on appl

Figure 35-2. Localized fire blight canker.



Weather affects the development of fire blight. Tempertures between 81° and 84°F are optimal for multiplicaon of the pathogen but it can develop over the range 9° to 90°F. The disease develops most rapidly when the elative humidity exceeds 60 percent. In general, the igher the temperature and humidity the shorter the inubation period, which is usually between 1 and 3 weeks.

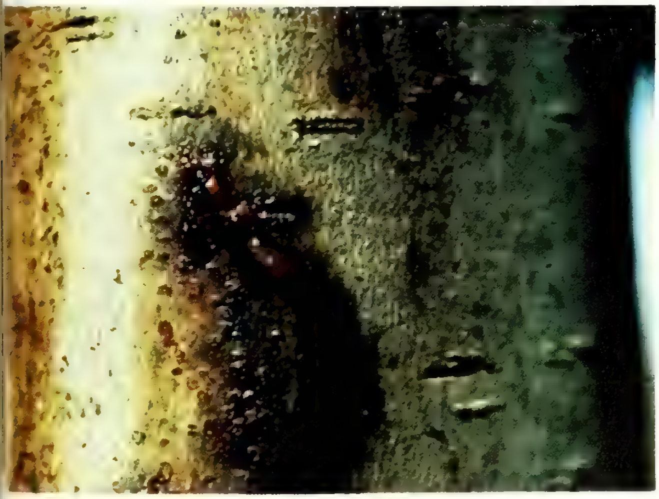
amage

Accurate estimates of losses from fire blight are difcult to obtain, but no doubt range in the millions of ollars annually. Fire blight is considered the most amaging disease of pome fruit in North America. nlike many other plant diseases, fire blight is destrucve to the current year's crops, and will cause permaent damage to the orchard. It is extremely dangerous the pear or apple industry in a fruit growing region.

In the 1970's, fire blight became prevalent on many oody ornamentals, especially cotoneaster. Restrictions n the export of these plants to other countries caused tremendous loss to the nursery industry. The loss of n established crabapple tree or cotoneaster hedge in the home landscape can be significant in terms of esthetic value, time, labor, and replacement costs.

igure 35-3. Symptoms of fire blight on cotoneaster.

igure 35-4. Amber-colored bacterial exudate oozing from fire blight canker.



Control

A blight prevention program involving dormant pruning, removal of diseased branches, and spraying with an EPA-labeled antibiotic or fungicide during flowering may reduce losses. Unfortunately, no one measure will control fire blight. When selecting orchard or landscape plants, try to exclude fire blight by selecting blight-resistant species or cultivars.

1. Sanitation and Quarantine – In areas where fire blight is severe, avoid planting apple and pear trees in the same orchard. This practice has reduced blight damage to apples.
2. Pruning – Remove and discard all twigs and branches with cankers. Branches should be cut at least 1 foot beyond the infected area. To surgically excise a canker, completely remove the bark in small sections over the canker surface, as well as healthy tissue 1 foot above and below the canker and 3 inches on either side. Pruning and surgical tools must be sterilized after each cut by dipping them into a disinfectant such as a 70 percent alcohol solution, or a household bleach solution of 1 part bleach to 9 parts water.
3. Tree Nutrition and Soil Management – Avoid stimulation of succulent growth in highly susceptible cultivars. Avoid heavy applications of nitrogen fertilizer or barnyard manure. Split nitrogen applications. Apply half the required amount to the soil one month before growth starts and the other half as a foliar or ground spray after petal fall. Strive to maintain a soil pH of 5.5 – 6.5 by liming.
4. Chemical Control – Copper compounds and antibiotics are effective in controlling fire blight. Apply all chemicals in compliance with Environmental Protection Agency regulations. Make an early season application at the green tip stage, and then repeat every 5 to 7 days beginning at the pink tip stage and continuing into postbloom.
5. Eradication – Susceptible plants should be examined 10 – 14 days after bloom for infected new blossoms. All infected spurs should be removed by cutting at least 6 inches below the farthest evidence of infection.
6. Biological Control – Control of fire blight by antagonistic organisms offers some potential; however, this measure presently is not effective enough to replace chemical treatments.

Selected References

Beer, S. V. Fire blight: Its nature and control. Inform. Bull. 100, New York State College Agriculture and Life Sciences; 1976. 15 p.

Blanchard, Robert O.; Tattar, Terry A. Bacterial diseases. In: Field and laboratory guide to tree pathology. New York: Academic Press; 1981: 181–191.

Van Der Zwet, Tom; Keil, Harry L. Fire blight – A bacterial disease of rosaceous plants. Agric. Handb. 510. Washington, DC: U.S. Department of Agriculture; 1979; 200 p.

36. Witches'-Broom of Hackberry

Mark O. Harrell and Frederick J. Crowe

Hackberry is commonly planted in cities and parks in much of the central Great Plains. Although principally a bottomland tree, it is able to withstand a wide range of moisture and temperature conditions and does well in an urban environment. A common and sometimes disfiguring branch disease of hackberry is witches'-broom.

Hosts and Distribution

Witches'-broom probably occurs throughout the range of hackberry in the Great Plains; it is very common in eastern Kansas and Nebraska. Its principal host is hackberry.

Winter surveys of northeastern Kansas city street plantings, showed between 40 and 75 percent of the hackberry trees had witches'-brooms. However, even though branches of mature, closely spaced hackberry trees penetrated and touched the canopies of each neighbor, many trees had remained broom-free for many years in spite of the fact that neighbors were heavily broomed.

Symptoms and Signs

The most apparent symptom of witches'-broom is a dense clustering or "brooming" of twigs. Because brooms do not occur on branches less than 1 year old they are not found at branch tips. They occasionally appear to be terminal, however, when a branch leader fails to develop fully or when it dies and breaks off. Buds of shoots within a broom are usually larger than normal and have more open bud scales.

The first indication of witches'-broom appears in the

Figure 36-1. Young broom on hackberry with numerous enlarged buds.

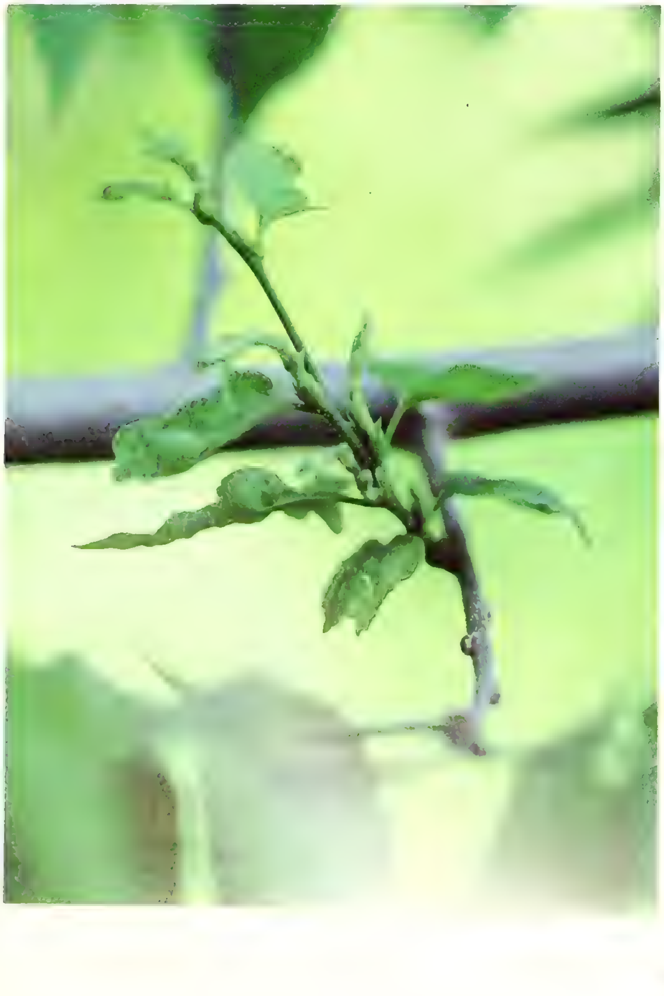
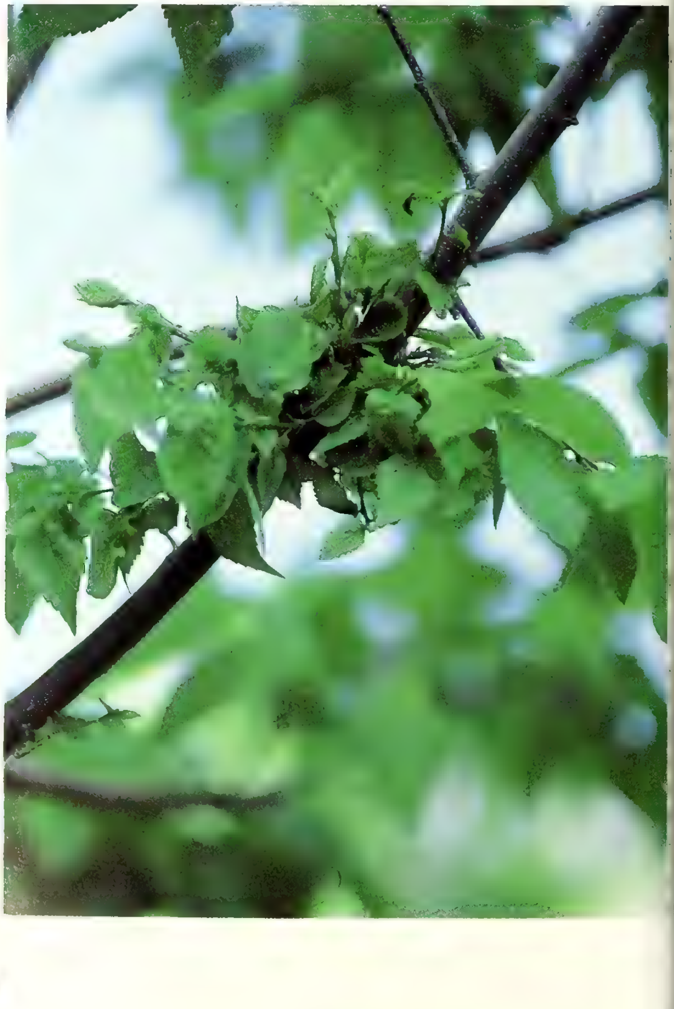


Figure 36-2. Young broom with open cluster of affected twigs.



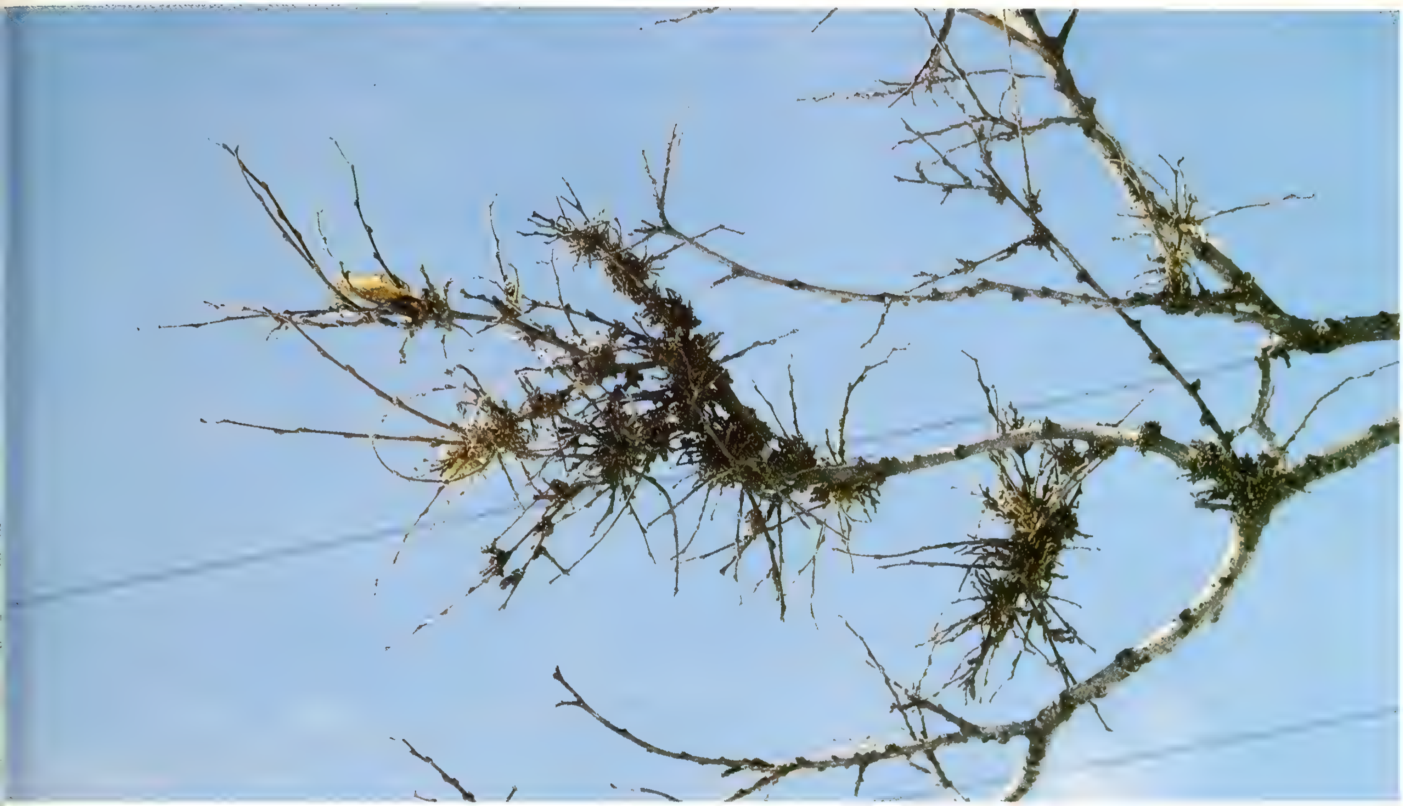


Figure 36-3. Old brooms with compact woody centers.

uds on branch portions at least 1 year old. The infected uds are usually smaller than normal, and often there re many small, swollen buds instead of a single large ne. The shoots produced from the diseased buds grow igorously and produce buds that are usually larger, nore open, and more numerous than normal (fig. 36–1).

During the following year the development of the room varies, depending upon the vigor of the diseased ranch. If the branch is vigorous and grows rapidly, its uds develop into branchlets similar to the original, and ver a number of years a loose or open cluster of disased twigs is formed (fig. 36–2). If the diseased branch s weak, only the buds at the base grow, resulting in a arge number of abortive twigs. Over several years this ype of development produces a compact broom with a irm woody center often an inch or more in diameter fig. 36–3).

isease Cycle

The cause of witches'-broom of hackberry is not nderstood. An eriophyid mite (*Aceria* sp.) rarely found n symptomless trees is almost always associated with e brooming; the powdery mildew fungus *Sphaerotheca hytophila* is much less often found. The original report f the mite/mildew association with brooms has comonly been misinterpreted as a requirement for the abormal development of witches'-brooms. However, there no experimental evidence to confirm or disprove the le of these organisms in the development of the disease.

Viruses and mycoplasma-like organisms (MLO's) also can cause brooming in woody plants. Whether the growth abnormality results directly from mite activity, whether the powdery mildew is involved but remains too obscure to be routinely identified, or whether a virus-like entity is instead responsible remains uncertain.

Damage

Witches'-brooms on hackberry are more unsightly than harmful to the tree. Brooms can cause branches to break more readily and therefore expose wood to decay fungi. Extensive brooming can reduce the vigor of the tree. However, trees are seldom seriously injured.

Control

No effective control measures are known for this disease. Pruning back diseased twigs to sound wood can improve the tree's appearance.

Selected References

Kellerman, W. A.; Swingle, W. T. Branch knot of the hackberry. Annual Report of the Kansas Experiment Station, 1888. Manhattan: Kansas State Agricultural College; 1889: 302–315.

Snetsinger, Robert; Himelick, E. B. Observations on witches'-broom of hackberry. Plant Disease Reporter. 41: 541–544; 1957.

37. Perennial Woodrotting Fungi that Cause Stem Decays of Hardwoods

Jerry W. Riffle and James A. Walla

A number of perennial polypore fungi other than those of the genus *Phellinus* cause stem decays. Most species that attack hardwood trees and shrubs in the Great Plains are classed either as white-rot or brown-rot fungi. White-rot fungi degrade cellulose and lignin, have extracellular phenol oxidases, and generally give positive oxidase tests with gallic and tannic acid media or with gum guaiac. Brown-rot fungi degrade cellulose and generally give negative oxidase tests.

Hosts and Distribution

Eleven species of polypores with perennial sporocarps are important decay fungi on hardwood tree and shrub species in the Great Plains. They have been classified in the genus *Fomes* in older literature. Five common species are discussed in this paper. Characteristics and distribution of these species are given in table 37–1. *Perenniporia fraxinophila* (fig. 37–1) is the most commonly reported stem decay fungus on live green and white ash in the Great Plains; it has been found on many other tree species, including bur oak and boxelder. *Perenniporia ellisiana* (fig. 37–2) is the most commonly reported stem decay fungus on live individuals of the genus *Shepherdia*. *Ganoderma applanatum* (fig. 37–3) and *Fomitopsis meliae* attack both live and dead hardwoods, including poplar, maple, honeylocust, and ash. *Fomes fomentarius* occurs principally on dead hardwoods, especially birch. Other, less-common species in the Great Plains include *Oxyporus populinus*, *Ganoderma lobatum*, *Perenniporia ohiense*, *Datronia scutellata*, and *Fomitopsis cajanderi*.

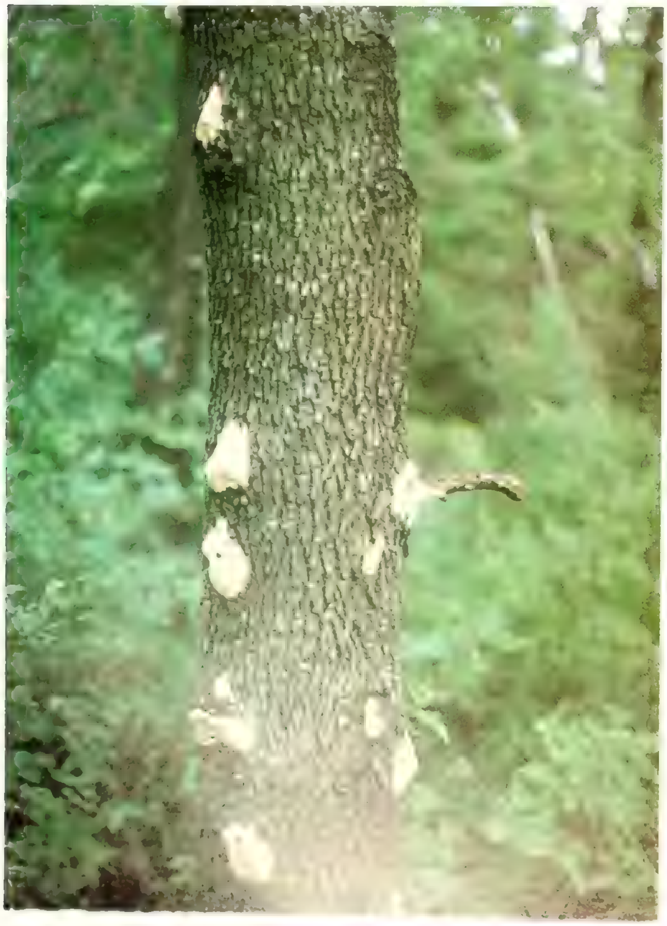


Figure 37-1. Sporocarps of *Perenniporia fraxinophila* on bole of a green ash.

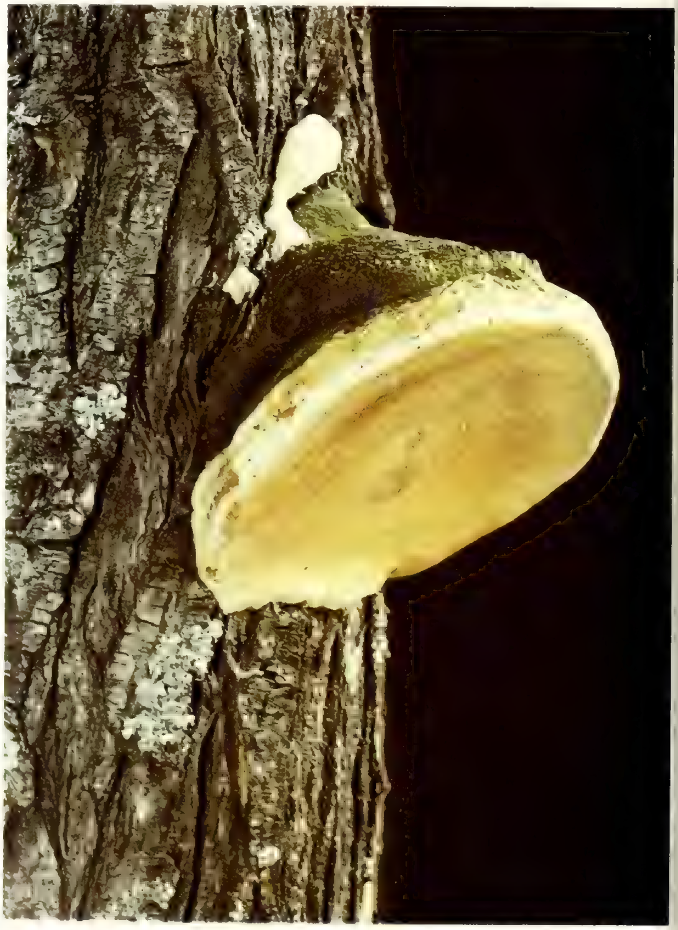


Figure 37-2. Sporocarp of *P. ellisiana* on stem of buffaloberry.

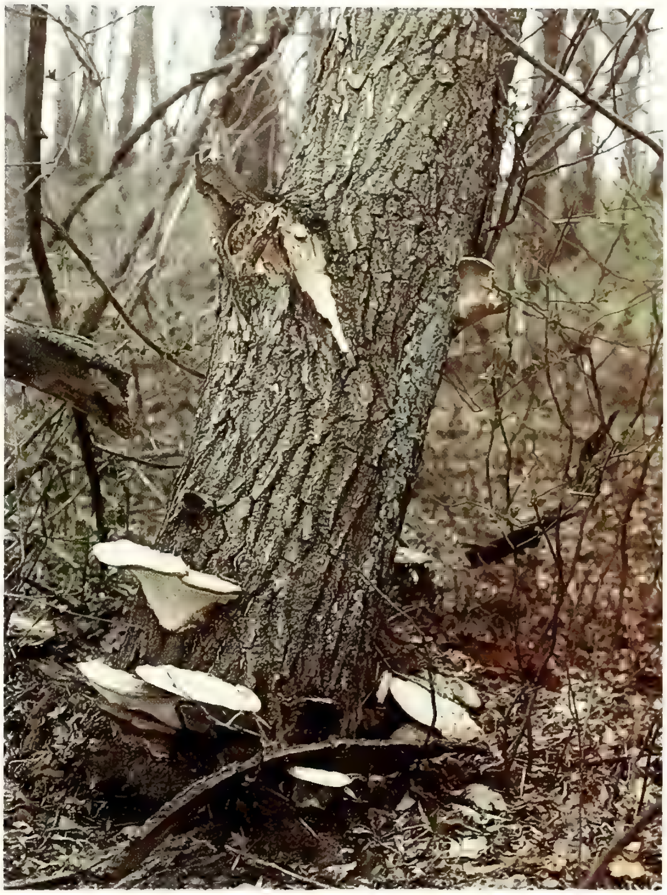


Figure 37-3. Sporocarps of *Ganoderma applanatum* on dead cottonwood.

Symptoms and Signs

Sporocarps (fruiting bodies) of decay fungi develop on boles or major branches of trees with extensive wood decay. Sporocarps of these polypores are perennial, hard and woody when mature, typically shelf- to hoof-shaped, sessile, and have well-developed tubes seen in a vertical section through the sporocarps. More than one layer of tubes can be seen in vertical cuts through the center of sporocarps that have sporulated more than 1 year.

Some macroscopic characteristics of sporocarps useful in identifying species of perennial polypores are the size, shape, and color of sporocarps, size of pores, and color and texture of the context (table 37–1). Microscopic characteristics of hyphal and hymenial elements also are useful for identification of species.

Most species of perennial polypores that infect live hardwood trees in the Great Plains eventually produce a white-mottled decay of the wood. Decay caused by *P. fraxinophila* on green ash is characterized by a wide, brown zone surrounding the advanced decay (fig. 37–4). Invaded tissues become light brown and later dark brown; decayed wood is then bleached until it becomes straw color to white. Finally, white spots appear in the wood and decayed wood becomes soft and crumbly. *G. applanatum* and *F. fomentarius* also produce a white or straw-colored wood decay. Wood decayed by *P. ellisiana* is brown, with small, irregular white flecks scattered

Table 37–1. Geographical distribution, and sporocarp and basidiospore characteristics of five species of perennial polypores that decay wood of hardwood trees and shrubs in the Great Plains.

Decay fungus[1]	Geographical distribution	Sporocarps					Basidiospores	
		Size, cm[2]	Shape	Pores per mm hymenium	Context color	Pore surface color	Size, µm[3]	Shape
Ganoderma applanatum	ND,NE,KS,MT,CO, NM,MAN.	3x5x1–30x50x10	Sessile, pileus plane or convex	4–6	brown, occas. white	white	5x4–9x6	ovoid,truncate at one end appearing ornamented
Perenniporia ellisiana	MT,WY,CO,NM, ND,SD,SASK.	3x3x1–10x15x8	Sessile, pileus convex to ungulate	2–3	pallid to wood-colored	white to isabelline	4x3–8x6	oblong-ellipsoid to broadly ellipsoid,truncate at apex
Perenniporia fraxinophila	MT,WY,CO,NM,ND, SD,NE,KS,OK,MAN.	2x3x1–25x40x10	Sessile or decurrent, pileus convex to ungulate	2–3	pale wood to yellow brown	white to brownish	6x5–9x6	ellipsoid to ovoid, truncate at end
Fomitopsis melliae	NE,TX	1x3x1–5x10x5	Sessile or decurrent pileus convex or plane, usually imbricate	4–5	cinereous to pale wood	isabelline	6x2–8x3	cylindric
Fomes fomentarius	MT,ND,SD,NE,MAN.	3x6x2–15x20x15	Sessile, pileus convex to ungulate	3–4	dark tan or brown	gray to brown	12x4–18x5	cylindric-ellipsoid

[1] *F. melliae* is a brown-rot fungus; the remaining four species are white-rot fungi.
[2] length x width x height
[3] length x width

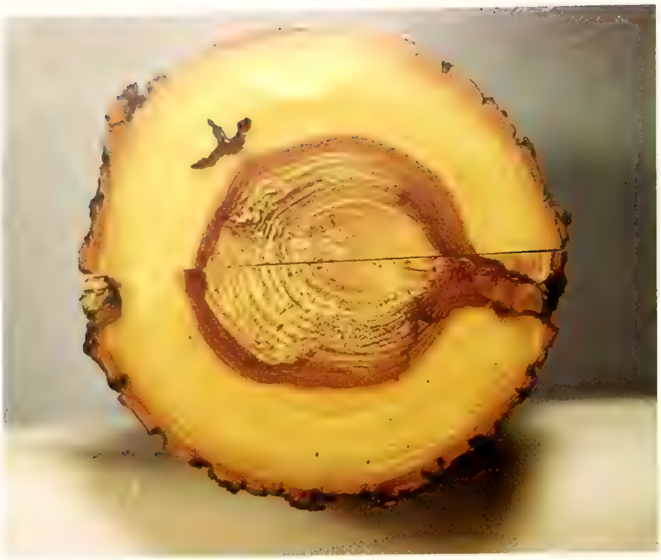


Figure 37-4. Cross section of green ash stem with white mottled decay caused by *P. fraxinophila.*

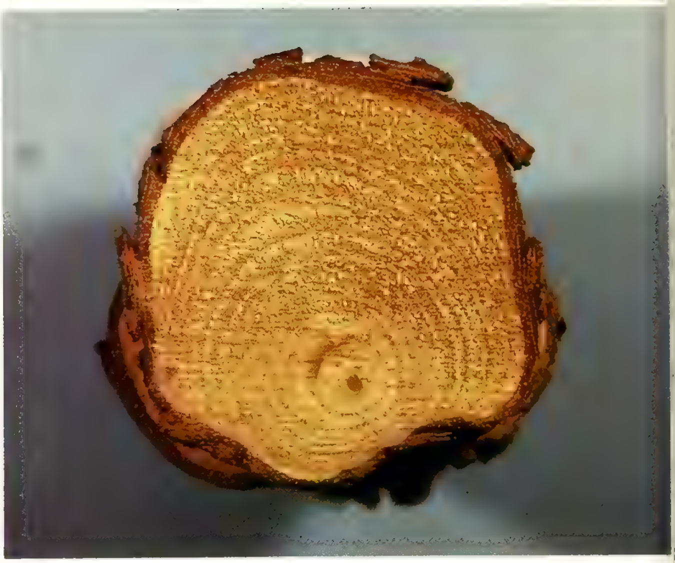


Figure 37-5. Cross section of buffaloberry stem with wood decayed by *P. ellisiana.*

throughout (fig. 37–5). *F. melliae* causes an extensive brown crumbly decay of sapwood of hardwoods.

Disease Cycle

Decay in trees is a complex process that begins at wounds, branch stubs, or other openings in the bark of boles or branches of trees. Many microorganisms, including bacteria, yeasts, and other nonhymenomycetous fungi, invade these openings in succession. Physical and chemical changes caused by these microorganisms in the invaded wood make it possible for wood decay fungi to become established. After growth and subsequent wood decay, sporocarps are produced to complete the life cycle. Discoloration and decay of wood by microorganisms are limited to wood present at the time of wounding by a barrier zone formed by the cambium. Additional wounding of stems may result in multiple infections.

Damage

Damage to hardwood trees by stem decay fungi becomes increasingly serious when trees reach the age at which tree vigor declines. These fungi seldom kill trees, but infected stems are more vulnerable to breakage during windstorms, and affected wood is not suitable for wood products.

Buffaloberry has been severely damaged by *P. ellisiana* in the northern Great Plains. This fungus may destroy windbreak plantings that are only 20 to 25 years old. Buffaloberry is so susceptible that its extensive use in the northern Great Plains is not encouraged.

At least 2 million of the 20 million living green ash in Nebraska woodlands are infected by *P. fraxinophila*. Incidence of green ash with sporocarps increases in a straight line relationship with diameter of the tree stem.

Control

Because the decay process begins with wounds, prevention of wounds—particularly basal wounds caused by grazing livestock and cultivating too close with machinery, removal of trees, or fires—will reduce development of decay in plantings and woodlands.

Landscape trees in urban areas and in recreational plantings occasionally are pruned to remove dead or diseased branches. It is advisable to cut small branches; do not cut through the callus collar at the base of the branches. Where it is impractical to prune trees, regulate tree spacing so that natural pruning will reduce the number and size of potential infection sites. When removing trees from plantings during thinning, removal of defective and diseased trees will help reduce storm damage and sources of inoculum.

Selected References

Lowe, Josiah L. Polyporaceae of North America. The genus *Fomes*. Tech. Pub. 80. Syracuse: State University College of Forestry at Syracuse University; 1957. 97 p.

Overholts, Lee Oras. Polyporaceae of the United States, Alaska, and Canada. Ann Arbor: University of Michigan Press; 1953. 466 p.

Riffle, J. W.; Ostrofsky, W. D.; James, R. L. *Fomes fraxinophilus* on green ash in Nebraska windbreaks. Plant Disease. 65: 667–669; 1981.

Riffle, Jerry W.; Sharon, Edward M.; Harrell, Mark O. Incidence of *Fomes fraxinophilus* on green ash in Nebraska woodlands. Plant Disease. 68: 322–324; 1984.

Walla, James A.; Riffle, Jerry W. *Fomes fraxinophilus* on green ash in North Dakota windbreaks. Plant Disease. 65: 669–670; 1981.

38. Phellinus Stem Decays of Hardwoods

Jerry W. Riffle and Kenneth E. Conway

Species of *Phellinus* are associated with white rots of woody plants, and generally give a positive oxidase reaction on tannic and gallic acid media or with gum guaiac solution. In older taxonomic publications, the species now placed in *Phellinus* are found in the genera *Fomes*, *Poria*, and *Polyporus*.

Hosts and Distribution

Ten species of *Phellinus* occur on hardwood tree and shrub species in the Great Plains. *P. gilvus* is usually found on wood of dead trees, but it is occasionally found on live green ash, black locust, maple, and willow. *P. tremulae* (fig. 38–1) is restricted to aspen. Its range in North America, north of Mexico, is approximately the same as the range of aspen. *Phellinus igniarius* attacks live hardwood trees, especially birch, but it also has been found on ash, black walnut, poplars, buckthorn, and willow.

P. tuberculosus (formerly *P. pomaceus*) (fig. 38–2) produces an extensive stem decay in live *Prunus* species, especially American and chickasaw plums. *P. punctatus* (fig. 38–3) occurs on both live and dead hardwood trees and shrubs; it decays wood of live green ash, Siberian peashrub, American plum, lilac, willows (golden, diamond, Bebb), black locust, and common buckthorn.

P. robineae (fig. 38–4), a white-rot fungus, produces an extensive yellow-brown decay of living black locust (fig. 38–5) in the central and southern Great Plains. *P. weirianus* decays wood of black walnut. *P. everhartii* usually occurs on live trunks of oak, whereas *P. conchatus* occurs on dead wood of hardwood species. *P. ribis* has been found on live *Ribes* spp. in North Dakota. The ten *Phellinus* species and their known distribution in the Great Plains and surrounding states are described in table 38–1.

Symptoms and Signs

Sporocarps (fruiting bodies) develop on trunks and branches of trees and shrub species that have extensive wood decay. Characteristics of sporocarps and spores

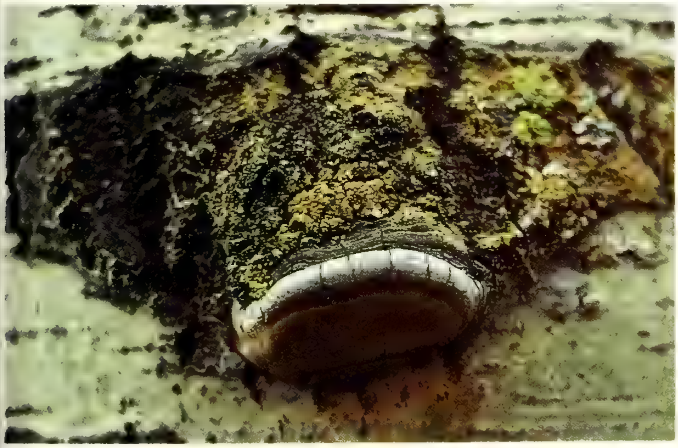


Figure 38-1. Sporocarp of *Phellinus tremulae* on bole of an aspen tree.

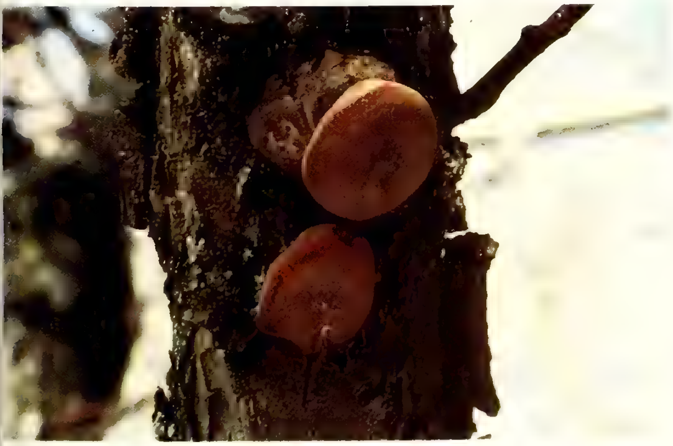


Figure 38-2. Sporocarps of *P. tuberculosus* on stem of American plum.

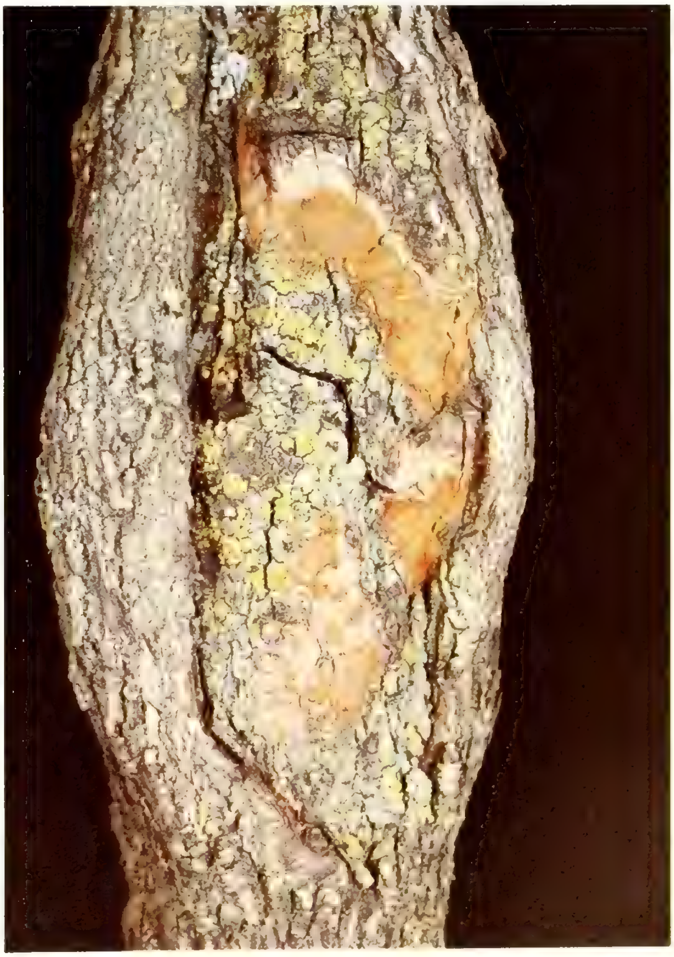


Figure 38-3. Sporocarps of *P. punctatus* and canker rot symptoms on bole of green ash.

Table 15-1 Geographical distribution and sporocarp and basidiospore characteristics of 10 *Phellinus* species that decay wood of hardwood tree and shrub species in the Great Plains.

[illegible]	Geographical distribution	Sporocarp characteristics					Basidiospore characteristics		
		Size, cm[1]	**Shape**	**Pores per mm hymenium**	**Context color**	**Pore surface color**	**Size, μm[2]**	**Shape**	**Colo**
[illegible]	MAN,ND,MT,TX	<1x4x<1-7x12x1	Mostly resupinate; sometimes sessile	5-7	yellow-brown or darker	yellowish-brown to dark brown	4x3-5x4	subglobose	hyaline
[illegible]	MT,NE,KS,NM	2x4x2-15x36x15	Sessile, pileus convex	4-6	rusty brown	yellowish-to reddish-brown	4x3-6x4	subglobose to globose	chestnut-brown in KOH
[illegible]	MT,ND,NE,KS, OK,TX,NM	1x2x<1-7x12x15	Sessile or effused-reflexed; pileus solitary or imbricate	6-8	bright yellow brown	dark purplish brown	4x3-5x3	ellipsoid to ovoid	hyaline
Phellinus igniarius	MT,ND,SD,NE, WY,CO,NM	3x5x2-15x20x12	Sessile or decurrent; pileus plane to convex	5-6	dark reddish brown	pale cinnamon brown to dark purplish brown	5x4-<1x5	broadly ovoid to subglobose	hyaline
Phellinus tremulae	CO,MT,NM,WY	up to 20x15	Sessile, developing at branch scars	6-7	dark reddish brown	purplish brown	4x4-5x4	subglobose	hyaline
Phellinus tuberculosus	MT,ND,NE,KS, OK,WY,CO,NM	<1x4x1-6x10x3	Sessile or effused-reflexed; pileus plane to convex	4-6	yellowish-brown to reddish-brown	dark yellowish- to reddish-brown	4x3-5x4	ovoid to broadly ellipsoid	hyaline
Phellinus punctatus	ND,NE,OK,CO	—	Resupinate, becoming widely effused	6-8	—	yellowish to grayish-brown	6x5-8x7	broadly ovoid to subglobose	hyaline
Phellinus ribis	MAN,ND, MT,KS	1x1x<1-10x20x4	Sessile or effused-reflexed	7-8	brown	gray-brown to dark brown	3x2.5-4x3	ellipsoid to globose	pale rusty
Phellinus robineae	NE,KS,OK, TX,NM	3x5x1-20x30x15	Sessile; pileus applanate to ungulate	7-8	light reddish brown	yellowish to reddish-brown	5x4-6x5	ovoid to subglobose; flattened on one side	reddish-brown
Phellinus weirianus	NE,KS,OK, NM,TX	up to 3x8x8	Sessile, usually ungulate, sulcate	5-7	yellowish-brown	golden brown	4x3-5x3	subglobose to ovoid	pale yellow brown

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[1] length x width x height
[2] length x width

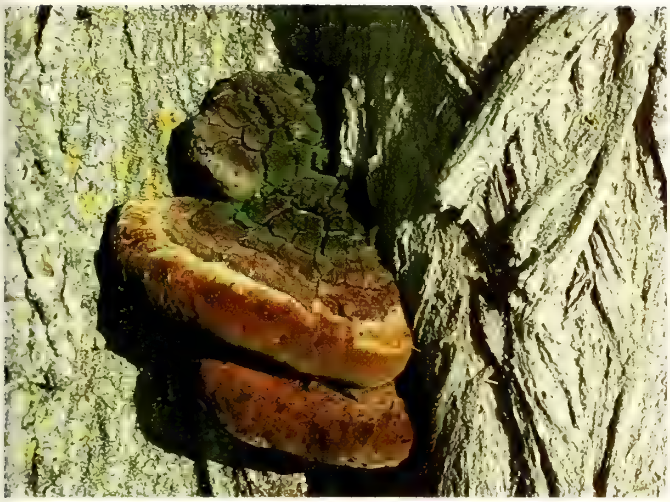


Figure 38-4. Sporocarps of *P. robineae* on bole of black locust.

that are useful in the identification of *Phellinus* species appear in table 38–1. Sporocarps are perennial, resupinate, effused-reflexed, or sessile. The context of the sporocarps is yellowish-brown to reddish-brown or purplish-brown, and darkens permanently to black in KOH solution. The hyphae may have simple septa but lack clamp connections. Setal hyphae and hymenial setae are present or absent; and basidiospores are cylindric to globose, and hyaline to pigmented. The pore surface is yellowish-brown to purplish-brown, and the pores are circular to daedaloid.

All *Phellinus* species cause a white-rot decay. Wood of aspen decayed by *P. tremulae* is initially light pink to straw-brown, then chocolate-brown, and finally is reduced to a soft, spongy, whitened mass. The decayed wood is surrounded by conspicuous dark zones or black lines. Wood invaded by *P. tuberculosus* initially becomes brownish with flecks and streaks, and finally becomes soft and stringy. *P. robineae* reduces wood of black locust to a soft spongy yellow or brown mass (fig. 38–5). The decay extends outward from the center of the heartwood in a series of radial lines along the rays. Red-brown mycelial felts characterize the decay. Decay by *P. gilvus* is confined mostly to the sapwood, which is tan or cream-colored when completely decayed.

Disease Cycle

The process of decay in trees is complex, and involves invasion of wounds by a succession of microorganisms, including bacteria, yeasts, other nonhymenomycetous fungi, and wood decay fungi. The development of decay in trees is discussed in article 37. Most of the species of *Phellinus* that decay wood of living trees are confined to the non-living heartwood of their hosts.

Damage

Many windbreaks established throughout the Great Plains in 1935–1942 during the Prairie States Forestry Project have reached an age of declining vigor, and damage from stem diseases has become increasingly serious. *P. robineae* occurs on black locust throughout the windbreak planting area in Oklahoma, and is the predominant stem decay fungus on this species. Incidence increases with tree age. About 25 percent of the black locusts in 40-year-old windbreaks in Oklahoma were infected with *P. robineae*.

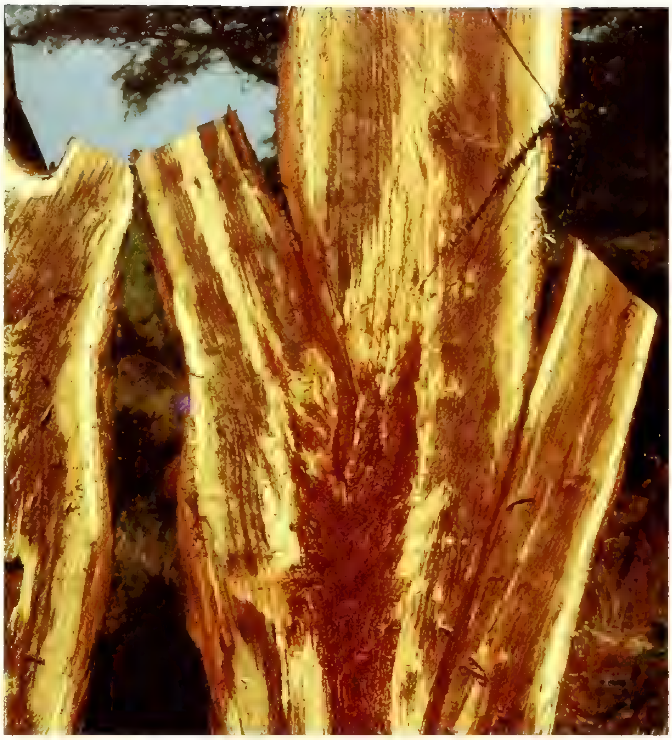


Figure 38-5. Longitudinal section of black locust with wood decayed by *P. robineae*.

P. punctatus is widespread in North Dakota, has a relatively wide host range, and occurs on about one-third of the sites that have hosts more than 20 years old. It has been found associated with canker rot on eight tree and shrub species in plantings and natural stands in the northern Great Plains. Based on sporocarp incidence, *P. punctatus* is the most important stem decay fungus on green ash in North Dakota Prairie States Forestry Project windbreaks.

Control

No direct control for stem decay fungi is known. Losses from these fungi can be minimized by use of certain preventative measures (see article 37 for such information).

Selected References

Gilbertson, R. L. The genus *Phellinus* (Aphyllophorales: Hymenochaetaceae) in western North America. Mycotaxon. 9: 51–89; 1979.

Riffle, Jerry W.; Myatt, Alan K.; Davis, Roger L. Incidence of *Phellinus robineae* in black locust plantings in Oklahoma. Plant Disease. 69: 116–118; 1985.

Walla, J. A. Incidence of *Phellinus punctatus* on living woody plants in North Dakota. Plant Disease. 68: 252–253; 1984.

39. Quince Rust

Kenneth E. Conway and Mark W. Andrews

Quince rust, caused by the fungus *Gymnosporangium clavipes*, was an economically important disease in the United States during the nineteenth and early twentieth centuries because of its devastating effects on commercial apple orchards. It can also severely infect *Juniperus* spp. Three rust fungi, *G. clavipes*, *G. juniperi-virginianae*, and *G. globosum*, infect apples and use *Juniperus* spp. as alternate hosts. The latter two *Gymnosporangium* species are discussed in another section of this handbook.

Hosts and Distribution

G. clavipes infects 11 genera of pomaceous hosts, including *Amelanchier* spp., *Amelosorbus* sp., *Aronia* spp., *Chaenomeles* spp. (flowering-quince), *Crataegomesphilus* sp., *Crataegus* spp. (hawthorn), *Cydonia* spp. (common quince), *Photinia* sp., *Pyrus* spp. (pear), and *Sorbus* spp. Some susceptible cultivars of apple are Delicious, Golden Delicious, Red Delicious, McIntosh, Northern Spy, Rome, and Winesap. Pycnial and aecial spore stages are developed on the pomaceous host. The telial and basidial spore stages occur on *Juniperus* spp.; no uredial spore stage is known.

Quince rust is not known to occur outside of North America, where it is found from Newfoundland to British Columbia and southward east of the Rocky Mountains to north Florida and Texas and into Mexico.

Symptoms and Signs

The disease on pomaceous hosts occurs most frequently on fruits, less frequently on twigs and buds, and rarely on leaves (fig. 39–1). Infection of apple leaves produce flecks or abortive lesions. Infected apples fall prematurely, and those that mature are misshapen and have dark green sunken lesions, usually near the blossom end. Unlike apples infected by the cedar apple rust fungus, tissue beneath quince rust lesions is necrotic, often deeply into the fruit.

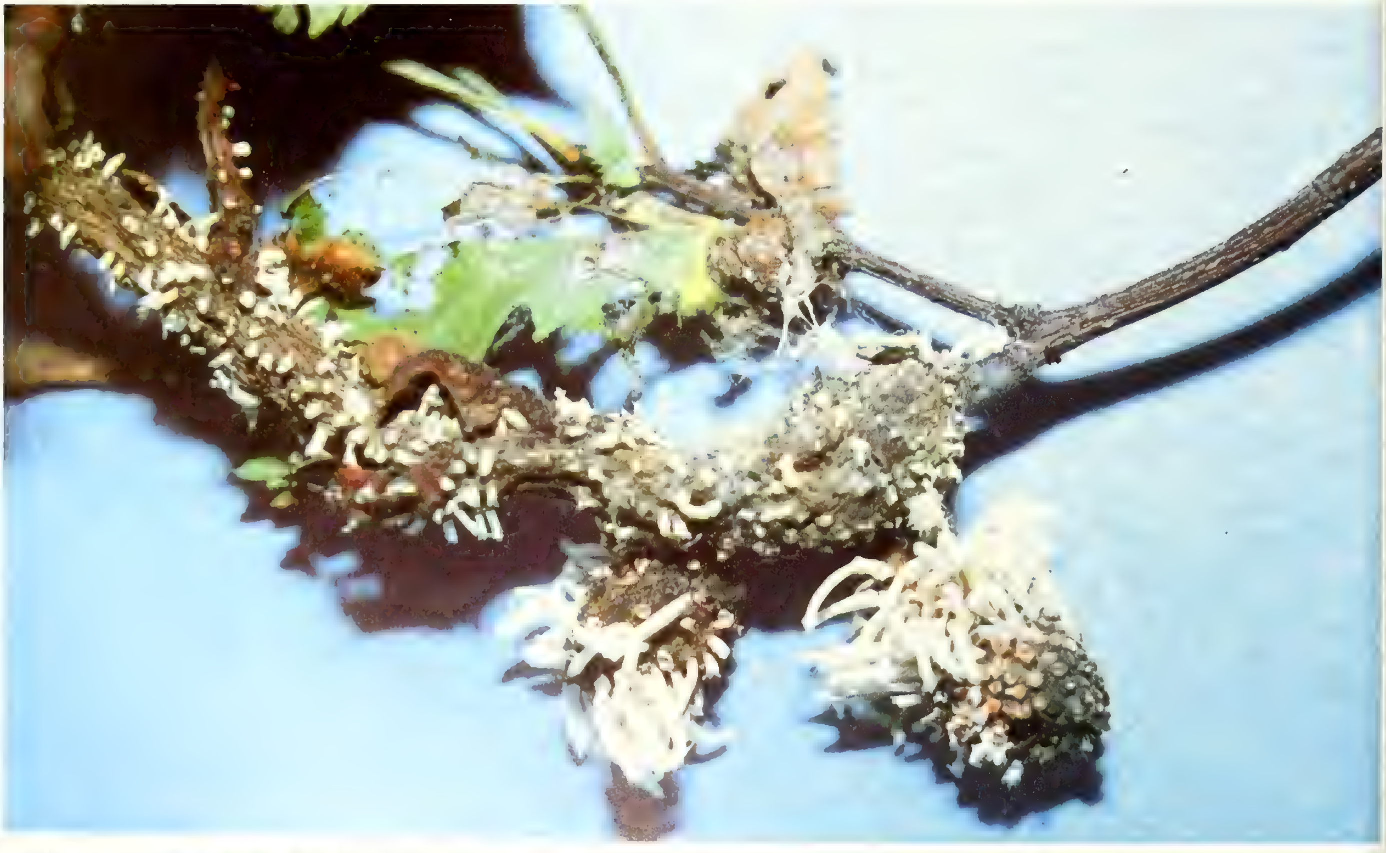


Figure 39-1. Aecia on fruit and [illegible] [illegible]ted by *Gymnosporangium clavipes*. Reddish-orange aeciospores visible when [illegible] white tubes are broken.

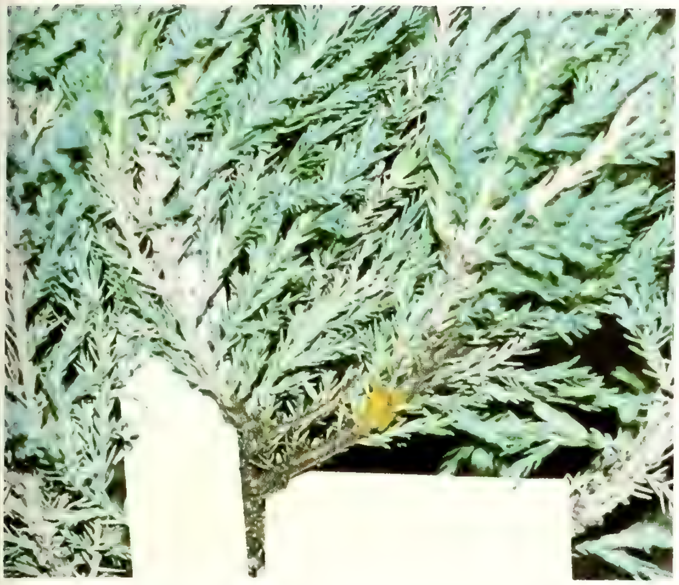


Figure 39-2. Dried gelatinous telial canker of *G. clavipes* on a branch of Andorra juniper.

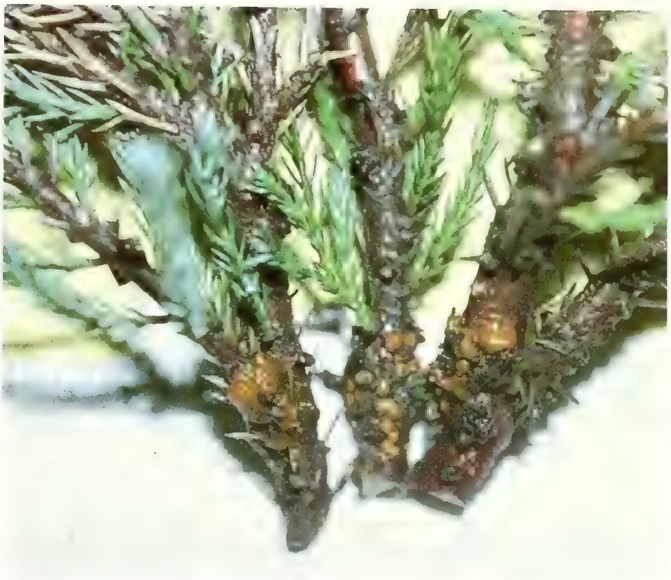


Figure 39-3. Gelatinous telial cankers of *G. clavipes* after moisture had been applied.

The quince rust fungus infects leaves, twigs, branches, and trunks of junipers. It produces elongate, swollen, often spindle- shaped rough cankers on twigs and branches. Reddish colored, gelatinous masses of teliospores exude from the cankers during rainy periods in the spring about the time apple trees are in bloom (figs. 39–2, 39–3). Five or six exudations are possible, but teliospores usually do not germinate to produce basidiospores during their first appearance. Teliospore and basidiospore masses change from red to yellow during this period.

Disease Cycle

The quince rust fungus requires two hosts to complete its disease cycle. Pomaceous hosts are infected by basidiospores discharged from germinated teliospores produced on juniper. Basidiospores are dispersed by wind, and infection occurs during a short period in the spring as flowers and fruit primordia emerge from their buds. After petal drop, fruits of most species are no longer susceptible. Pycnia develop 2 or 3 weeks after infection. Two or 3 weeks later, aecia are formed. The aecia are the most easily recognized of the spore stages (fig. 39–1) because long white tubes are formed that may cover the entire fruit. Aecia rarely form on apple, but are common on fruit of quince and hawthorn. When the tubes rupture at their apex, red masses of aeciospores are evident. Aeciospores are wind blown, and can infect junipers throughout the growing season.

Aeciospores infect leaves, twigs, and branches of juniper. Infected leaves are often overlooked. Twigs can become infected directly, and spindle-shaped swellings covered by flaky, darkened bark are formed. The fungus can remain active for several years as the cankered area continues to expand. Twigs infected during the growing season produce teliospores and basidiospores the following spring and annually thereafter.

Damage

Pomaceous hosts can be weakened by defoliation when leaves are severely infected. However, the greatest economic loss is caused by infection of fruits.

Twig and branch infection of juniper is limited to phellogen, but may cause some structural weakness. Severely infected trees may be more susceptible to winter injury. Failure to control quince rust on nursery junipers can result in quarantines and loss of revenue.

Control

Classical control has been the removal of junipers around apple orchards, and of pomaceous hosts around tree nurseries. Resistant varieties of apple and juniper are available. Pruning telial cankers on juniper can reduce disease potential, but large trees may have extensive trunk cankers that cannot be pruned out. Protective fungicide controls to prevent infection are available for apple (benomyl + mancozeb or zineb) and juniper (Bordeaux mixture or cycloheximide). To be effective, chemicals should be applied to apple in the spring as green tip and cover sprays. Junipers should be protected throughout the summer and fall on a regular basis.

Selected References

Anderson, Harry Warren. Diseases of fruit crops. New York: McGraw-Hill; 1956. 501 p.

Crowell, I. H. The hosts, life history and control of *Gymnosporangium clavipes* C. and P. Journal of the Arnold Arboretum. 16: 367–410; 1935.

Kern, F. D. Lists and keys of the cedar rusts of the world. Memoirs, New York Botanical Garden. 10: 305–326; 1964.

Miller, Paul R. Pathogenicity of three red-cedar rusts that occur on apple. Phytopathology. 22: 723–740; 1932.

40. Environmental Stress Effects

Donald F. Schoeneweiss

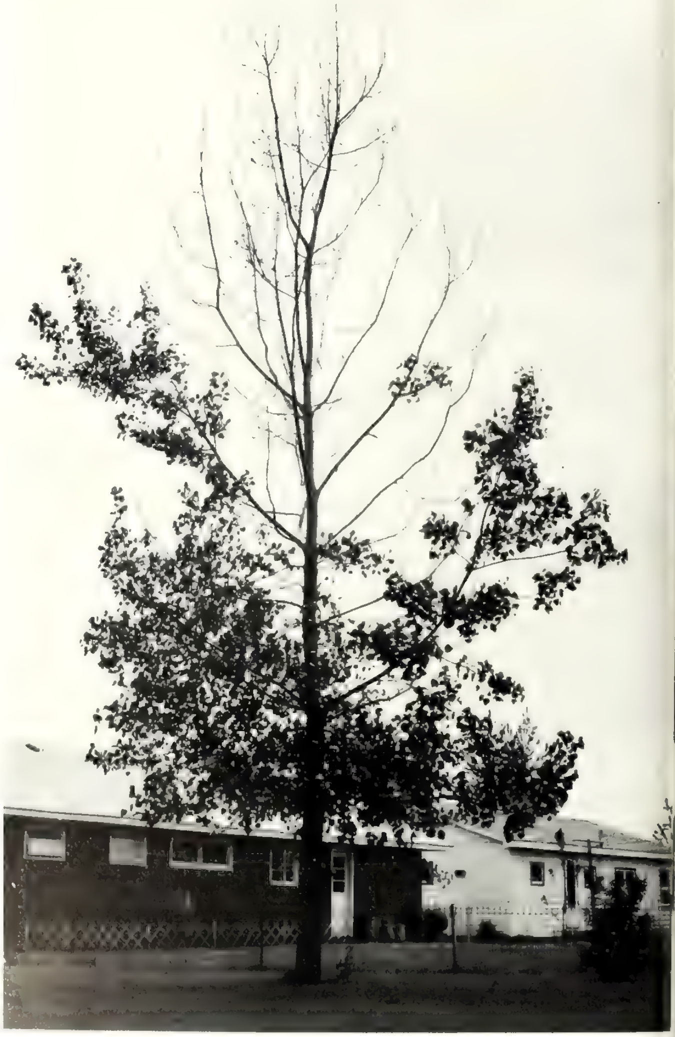
Trees are long-lived plants that endure through many years of climatic changes. Some, such as the redwoods and Sequoias of the West Coast and the bristlecone pines of the high Sierras, are the oldest living things on earth. To survive through hundreds or even thousands of years of drought, freezing, blizzards, and high winds, trees must be somewhat resistant or adaptable to extreme climatic conditions. Because of this great longevity, people automatically attribute most tree injuries to attack by parasitic disease organisms. After all, how can a tree that has been growing in the same site for decades be injured by drought or freezing?

To comprehend the role of environmental stress in tree diseases, one must know how trees grow and what relationships exist between various plant parts and their surrounding environment. As a tree seedling becomes established in a site, the root system attains an increasingly delicate balance with the root environment or rhizosphere. Initially, roots may penetrate soil to a considerable depth; but as the tree approaches maturity, the bulk of the feeder root system on which the tree depends for water and nutrients concentrates throughout the upper layers of soil, often within a few cm of the surface depending upon soil type, tree species, and soil moisture. Because the surface layers of soils are more subject to variations in temperature, moisture, and aeration than deep layers, environmental stresses may have more injurious effects on large, mature trees than on younger, deeper-rooted saplings. For example, a woodlot of century-old white oaks may show symptoms of dieback and decline following a prolonged drought, while smaller trees retain enough vigor to recover once the stress is relieved.

Another important factor to consider in understanding tree diseases is that woody perennial plants resist the damaging effects of environmental stresses predominantly through the hardening or acclimation of tissues. Buds, living stem tissues, and, to some extent, roots enter dormancy in the fall and become increasingly resistant to freeze damage as days become shorter and temperatures drop below freezing. In some cases, trees subjected to mild drought early in the growing season will drought-harden and become more resistant to succeeding droughts of greater severity. Trees suffer more damage if they are not sufficiently hardened when stress conditions occur.

Two types of damage may result from environmental stresses: direct damage due to the injurious effects of stress on host cells, and indirect damage that involves attack of injured or weakened cells by plant parasites (figs. 40-1 to 40 [illegible]) [illegible] succulent plants, are relatively resistant to stress and are able to harden under certain conditions, direct damage usually results only from rather severe levels of stress. However, even moderate stress levels can have pronounced effects on the susceptibility of trees to attack by disease parasites. When the susceptibility of a tree to parasitic attack increases as a result of unfavorable environmental factors, it is said to be "predisposed." The most common and effective predisposing environmental factors affecting trees are temperature and soil moisture.

Figure 40-1. Direct damage on cottonwood injured by a hard fall freeze.



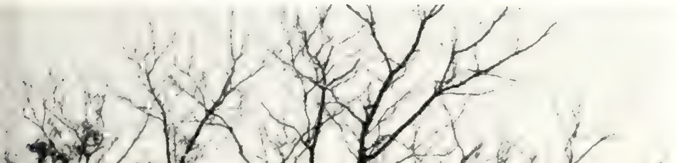
High and Low Temperatures

Direct Damage:

High temperatures seldom cause significant damage to trees in the Great Plains. Succulent leaves and shoots may wither and blacken when exposed to unusually high temperatures but the damage is rarely permanent. Exposure of thin-barked stems to bright hot sun in winter may cause sunscald if bark tissues are killed to the cambium. Sunscald may also appear on tender bark of shaded branches that are suddenly exposed to bright sun following thinning or pruning operations. Stem tissues killed by sunscald are often invaded by fungi and boring insects. High temperatures usually combine with bright sun to increase water loss from foliage; consequently, damage associated with heat is more often due to water stress than heat stress per sé.

Low temperature injury to trees in the Great Plains is usually the result of exposure to subfreezing temperatures. Even very hardy tree species can be injured by freezing when an extended period of mild weather is followed by a sharp drop in temperature to near zero (fig. 40–5). Such extreme temperature changes are characteristic of the Great Plains, particularly in the fall before trees have become fully acclimated to low temperatures. In the spring, trees lose cold hardiness rapidly during warm weather and can be severely injured by a hard freeze. Symptoms of direct damage by freezing include bud kill, browning of evergreen foliage, dieback, frost collars at the base of trunks, frost cracks, and splitting of bark on frozen branches. A symptom often associated with freeze damage is prolific growth in spring of suckers on the trunk and branches of injured trees. Because the root systems of plants do not harden to temperatures much below freezing, root kill may occur during cold periods in the absence of an insulating cover of snow or leaf litter.

Figure 40-2. Indirect damage on drought-stressed honeylocust due to girdling cankers caused by *Nectria cinnabarina.*



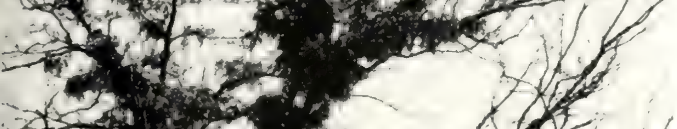


Figure 40-3. *N. cinnabarina* canker of honeylocust.

Indirect Damage:

High temperatures alone seldom lead to indirect damage by parasites on trees unless tissues are killed or severely injured. In fact, during hot weather foliar diseases, which require prolonged periods of moisture films on leaf surfaces for infection, are usually less of a problem. However, high temperature combined with high moisture when succulent tissues are present may result in increased damage by fungi and bacteria that cause blights. A more significant effect of high temperature in indirect damage involves increased drought stress usually associated with hot, dry weather.

Low temperatures can be quite effective in predisposing trees to attack by parasites. Although direct damage may result from freezing of plant tissue, the indirect effects of freezing are far more common. Outbreaks of canker diseases, collar rots, and diebacks because of attack by fungal and bacterial parasites are symptoms of indirect damage. The fact that freezing can predispose trees to parasitic attack at levels too moderate to cause direct damage means that the appearance of disease damage may be the only outward sign of freezing stress.

High and Low Soil Moisture

Direct Damage:

High soil moisture or flooding over a prolonged period can cause significant damage to tree roots. Although tree species vary in their sensitivity to changes in soil moisture, all tree roots require adequate aeration (a constant exchange of gases in the rhizosphere). When excess moisture blocks or reduces soil porosity for an extended period and creates anaerobic conditions, toxic metabolites accumulate in roots and cause damage. Flooding of tree roots also results in a reduction of water and nutrient uptake; consequently, affected trees may wilt or become chlorotic. Other symptoms associated with high soil moisture or "wet feet" are enlarged lenticels near the base of the main stem on saplings and the

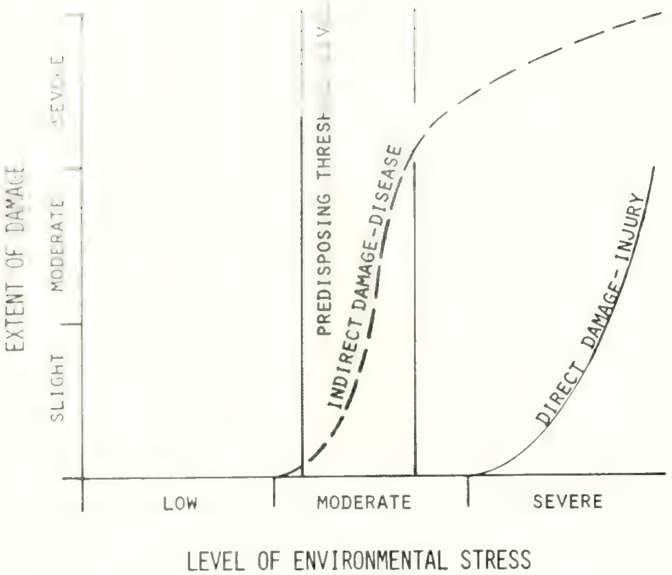


Figure 40-4. Relation of stress level to extent of damage.

formation of new roots near the soil surface where better aeration occurs. When a tree produces very shallow new roots and the older, deeper roots become blackened, high soil moisture is likely the cause of damage.

Low soil moisture or drought is a very common environmental stress in the Great Plains. Trees may be damaged directly by a severe seasonal drought, or damage may be cumulative over several consecutive years of below normal rainfall. Most trees injured directly by drought exhibit wilting symptoms, often accompanied by leaf drop, and may eventually die back from the branch tips. Necrosis of interveinal tissues and/or leaf margins, a condition known as "scorch," is often a symptom of drought damage. Drought and flooding both result in a reduction in root absorptive capacity and aboveground symptoms may be quite similar.

Indirect Damage:

High soil moisture effects on susceptibility of trees to parasitic attack have not received much attention from researchers. However, outbreaks of stem cankers and declines have been observed following prolonged periods of standing water or several consecutive years of abnormally heavy rainfall.

Low soil moisture or drought, in contrast, has been the subject of considerable research relating environmental stress to attack by parasites. Boring insects and bark beetles are attracted to drought-stressed trees and many stem canker fungi attack trees predisposed by drought. The level and duration of drought stress required for predisposition may be sufficiently moderate that no visible signs of stress appear, except for increased attack by parasites.

Additional [illegible]

Rust and mildew fungi, vi[illegible] [illegible]plasmas, and nematodes are obligate parasites that cause damage predominantly on vigorous trees, as do facultative fungi and bacteria that blight soft tissues. The opposite is true of most facultative parasites, which include many of the fungi and bacteria attacking stems and roots of trees. These organisms usually cause increasing amounts of damage as trees become stressed. Some are aggressive pathogens on vigorous trees but cause even more damage if trees become weakened. Others, including many stem canker and dieback fungi and bacteria and several root rot fungi, are nonaggressive parasites that normally grow saprophytically on dead and dying plant parts. If trees become stressed beyond a predisposing threshold level, they attack weakened tissue and cause damage. For example, it is quite common to find stem cankers forming around a branch stub, wound, or dead bud (fig.40–3) where the pathogen has been growing as a saprophyte.

Perhaps the greatest problem in identifying the causes of both parasitic and nonparasitic tree diseases is the long delay that often occurs between the cause of a disease problem and the appearance of damage symptoms. Damage from a hard fall freeze may not be apparent until well into the next growing season, particularly if the damage involves attack by parasites. Disease symptoms may continue to appear throughout the summer. Drought damage also may not be apparent for months or even years after the drought has ended. Large trees injured by drought may decline slowly over several years with increasing attack by disease organisms and boring insects. Accurate weather records are often of great help in the diagnosis of tree problems.

Many other factors such as nutrient deficiencies, herbicides and toxic pollutants, soil compaction, storm damage, and defoliation, alone or in combination with drought or freezing, may result in direct or indirect damage to trees. Most stresses weaken the entire tree, and the type of damage that appears may depend upon what parasites are present and what parts of the plant they attack. The main exception is freezing stress. Only tissues subjected to injurious temperatures are damaged; those insulated by snow cover or other temperature barriers remain healthy and resistant to parasites. Also, older wood tissues are more sensitive than bark and cambium to freezing stress in winter. The condition known as "blackheart" in trees is a result of freeze-damaged wood becoming susceptible to attack by fungi present deep in the wood.

Prevention of Stress-Related Damage

It is usually impossible and almost always impractical to prevent environmental stresses in forest trees. Shade and ornamental trees, however, have high per unit value and may warrant considerable time, effort, and money for their protection. Because direct damage usually occurs only if trees are severely stressed, even minimal maintenance in the form of watering, pruning, and fertilizing may afford protection from nonparasitic damage. Hardy trees, particularly species and varieties selected for disease resistance, when planted into well drained

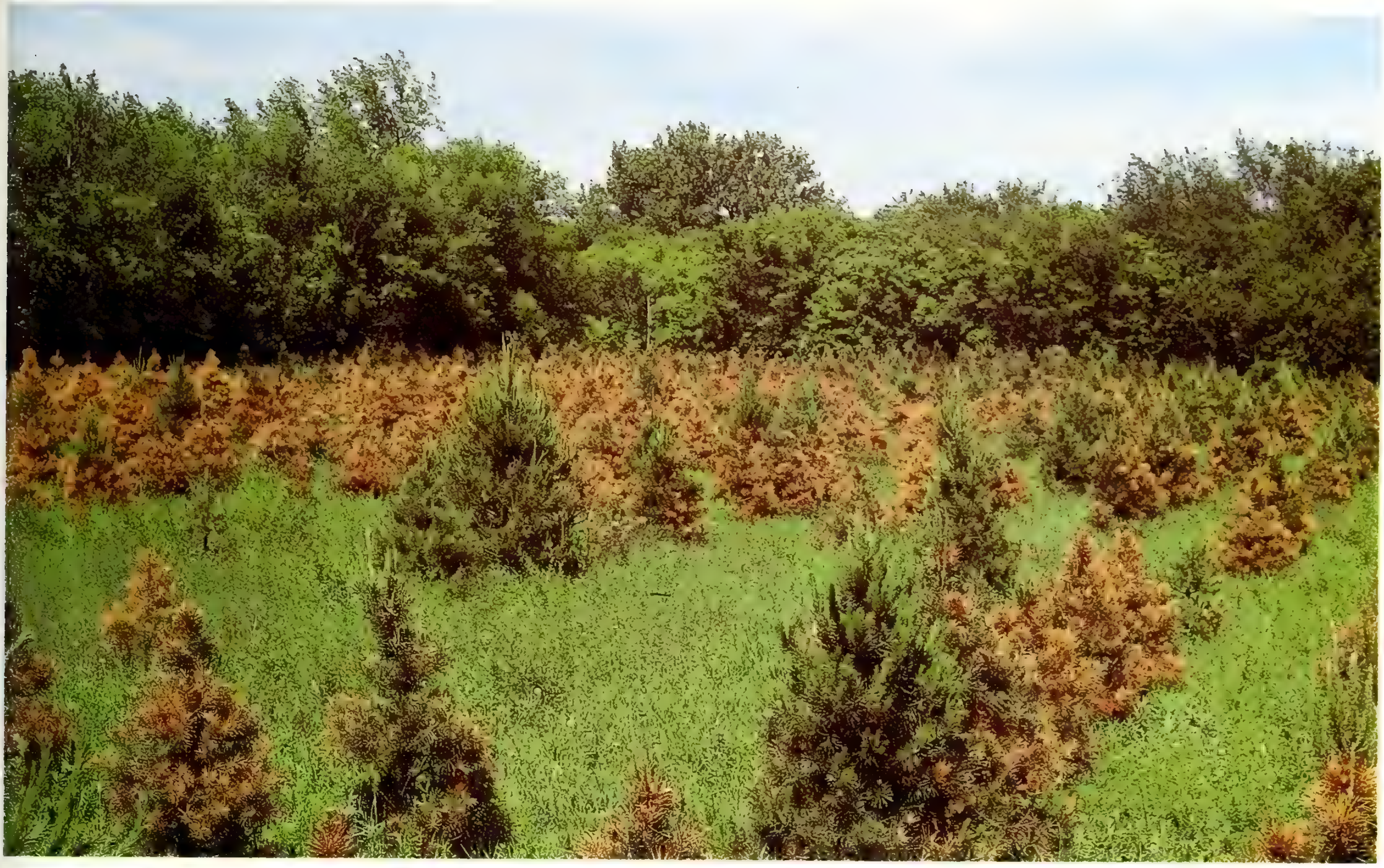


Figure 40-5. Winter burn on Scots pine in a planting in North Dakota.

fertile soil, are much less subject to nonparasitic and parasitic damage than those planted on marginal sites. Practices that favor plant vigor and the development of a proper shoot/root ratio should be employed. However, those that delay hardening or promote succulent growth at the wrong time, such as pruning or shearing before plants enter dormancy and applying high nitrogen fertilizer in late summer, invite stress damage and should be discouraged.

Treatment of Stress-Damaged Trees

As long as the tree remains stressed beyond a threshold level for infection, which may be relatively moderate stress, parasites may continue to cause damage. Therefore restoration of vigor is of prime importance in preventing further damage. If a tree is not killed by stress, it will begin to recover and heal once the stress is relieved. Dead or severely injured branches should be removed as soon as possible, since these tissues may be attacked by parasites that can cause further damage on weakened stems. In addition, disease organisms can remain viable for weeks or months in woody tissue even after healing has occurred and may resume activity and spread to healthy tissue if the tree is again predisposed by stress. Infected plant parts should, therefore, be removed and destroyed. Wound dressings are now seldom recommended because recent studies have shown that they do not aid in healing and may in fact provide conditions conducive to infection.

Many of the parasites that attack stressed trees are referred to as "secondary organisms," implying that they are not the cause of damage. Yet trees will often recover from predisposing stress without injury if these parasites are not present. Indirect damage from stress is therefore a combination of physical and biological factors. Most fungal and bacterial pathogens of trees are wound parasites that do not penetrate intact plant surfaces. During wet weather they produce large masses of infective spores or cells in diseased tissues that easily spread to fresh wounds on healthy plants. Diseased plant parts should be removed and destroyed only during dry weather to eliminate the sources of further infections, and tools and equipment should be cleaned and disinfected regularly.

Selected References

Schoeneweiss, Donald F. Predisposition, stress, and plant disease. Annual Review of Phytopathology. 13: 193–211; 1975.

Schoeneweiss, Donald F. The role of environmental stress in diseases of woody plants. Plant Disease. 65: 308–314; 1981.

Tattar, Terry A. Diseases of shade trees. New York: Academic Press; 1978. 361 p.

41. Dutch Elm Disease

Robert W. Stack and John G. Laut

Dutch elm disease is a systemic vascular wilt disease caused by the fungus *Ceratocystis ulmi*. Its presence was first confirmed in North America in Ohio in 1930. By the 1980's it had been found in all parts of the United States except the desert Southwest, and in eastern and central Canada.

Hosts and Distribution

C. ulmi is exclusively a parasite of trees in the elm family (Ulmaceae). Among 28 species of elms tested, the response ranged from highly resistant to highly susceptible. Among other genera in the elm family, including species of *Celtis* and *Zelkova*, only *Z. carpinifolia* was susceptible; all others were highly resistant or immune. Elm species native to the Great Plains include American (white) elm, rock elm, slippery (red) elm, winged elm, and cedar elm. The first four are susceptible to the Dutch elm disease fungus and are killed outright; the cedar elm, native to the southern Plains, is susceptible although some resistant individuals may occur.

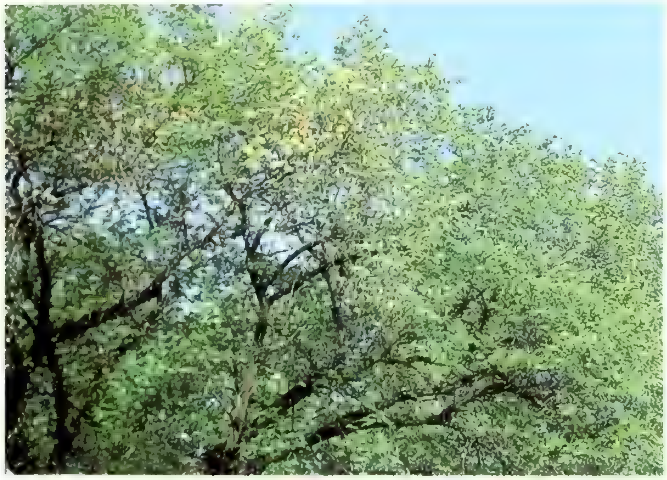


Figure 41-1. Yellowing of foliage is an early symptom of Dutch elm disease in American elm.

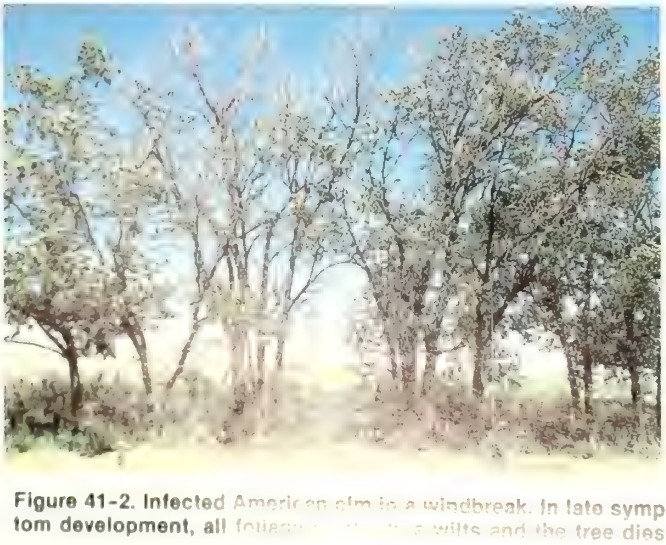


Figure 41-2. Infected American elm in a windbreak. In late symptom development, all foliage [illegible] wilts and the tree dies.

Of several exotic elms that have been planted on the Plains, the most common is Siberian elm, which has been widely used in shelterbelts, on farmsteads, and in urban plantings. The Siberian elm, as it occurs on the Great Plains, is best considered moderately tolerant to Dutch elm disease. Among other Asiatic elms, *Ulmus japonica*, *U. laciniata*, and *U. villosa* contain a high proportion of resistant trees. The Chinese or evergreen elm, *U. parvifolia*, is highly resistant or immune to Dutch elm disease. Several European elm species and hybrids are moderately resistant, but they are not climatically adapted to the Great Plains and are seldom planted here. There are several active tree breeding programs in the United States, Canada, and Europe, attempting to produce elm hybrids or selections that are resistant to Dutch elm disease. Several trees from these programs are already being tested and more can be expected in future years.

Symptoms and Signs

In a susceptible species such as American elm, the first symptoms of Dutch elm disease are yellowing of foliage (fig. 41–1), followed by wilting and browning. Usually a single branch is affected first; the symptoms then spread to adjacent branches. Later, one whole part of the tree may be symptomatic, and the entire tree finally wilts and dies (fig. 41–2). This progression of symptoms may develop in a single season in highly susceptible individuals, but often takes several years.

The fungus is strictly a vascular parasite, invading the xylem vessels of the host tree. It can persist in wood for several years after the tree dies. When bark on infected branches is peeled back, brown streaks in the wood indicate the presence of a vascular infection (fig. 41–3). Other wilt-causing fungi may also cause streaking of the wood, so this symptom is not entirely diagnostic for Dutch elm disease. Positive diagnosis requires a laboratory test in which chips of wood (not bark) from streaked branches are placed in a moist chamber for 7–10 days. Under these conditions, the coremia—fruiting structures of the *Pesotum* (formerly *Graphium*) stage of *C. ulmi*—will be produced on the chips (fig. 41–4). These coremia appear as dark stalks 2–5 mm high, supporting a pale globose ball of slime containing the spores.

Disease Cycle

Like most members of the genus *Ceratocystis*, *C. ulmi* is uniquely adapted for, and entirely dependent on, vectored transmission from tree to tree. There are two vectors for the Dutch elm disease fungus in North America, the native elm bark beetle, *Hylurgopinus rufipes*, and the lesser European elm bark beetle, *Scolytus multistriatus*. Both of these beetles feed and breed under the bark of living or recently dead elm trees or logs. As they fly from infected trees, they carry the spores of the Dutch elm disease fungus and introduce it to healthy trees as they feed. Both species of elm bark beetles are effective vectors.

The cycle of infection by the causal fungus is tied to the life cycle of the vectors. The beetles breed in recently dead elm wood or weakened living trees. If the fungus is present in such breeding sites, emerging beetles will carry spores of *C. ulmi* to healthy elms and introduce the fungus in feeding sites on young twigs. The beetles can fly up to 1/4 mile in search of feeding or breeding sites, but they may be blown many miles by winds.

Damage

The American elm (*U. americana*) was native along river valleys throughout the Great Plains. Because it had many desirable qualities, was easily handled, and grew rapidly, early settlers planted American elm in their cities and towns, on farmsteads, and later in windbreaks. Most of these plantings, as well as large areas of native elms, have now been lost to Dutch elm disease over much of the Great Plains. Only in the very northern and southern parts of the Great Plains do elms remain in substantial numbers. The cost to cities and towns just for removing dead elms was tremendous, and continues to be so where elms remain. The cost of losing an excellent species for farmstead windbreaks cannot be calculated, and the effect of removing one of the dominant species from the riparian forest is probably significant but completely unknown.

Control

To date there is no cure for Dutch elm disease, and the term control is a misrepresentation of what can be done; the term "Dutch elm disease management" most accurately represents the state of the pathologists' art. In urban areas, an effective sanitation program can reduce the rate of tree loss due to Dutch elm disease to a level the community can live with, allowing for gradual replacement of the trees. In rural communities, windbreaks, and native woodlands, little can be done to forestall the loss of the elm.

Individual high-value trees may be protected by injection of chemical fungicides at 1- to 3-year intervals. These materials can provide reasonable protection, but they are expensive and the repeated wounding from injections may eventually damage the tree seriously. The success of these treatments for therapy of infected trees is much more limited. They may be worth trying on very high value trees but have little prospect for general use.

Some elm species have high levels of resistance to infection by *C. ulmi*. Selections or hybrids from these resistant parents have been released to the trade, but some may lack the climatic adaptability needed for good growth and longevity under Great Plains conditions. Large scale use should be deferred until wider testing has been done.

Selected References

Gibbs, John N. Intercontinental epidemiology of Dutch elm disease. Annual Review of Phytopathology. 16: 287–307; 1978.

Kondo, E. S.; Hiratsuka, Y.; Denyer, W. B. G. Proceedings of the Dutch elm disease workshop and symposium. Winnipeg: Manitoba Department Natural Resources; 1982. 517 p.

Sinclair, W. A.; Campana, R. J., eds. Dutch elm disease: Perspectives after 60 years. Ithaca, New York: Cornell University Agricultural Experiment Station. Search (Agriculture) 8(5): 1–52; 1978.

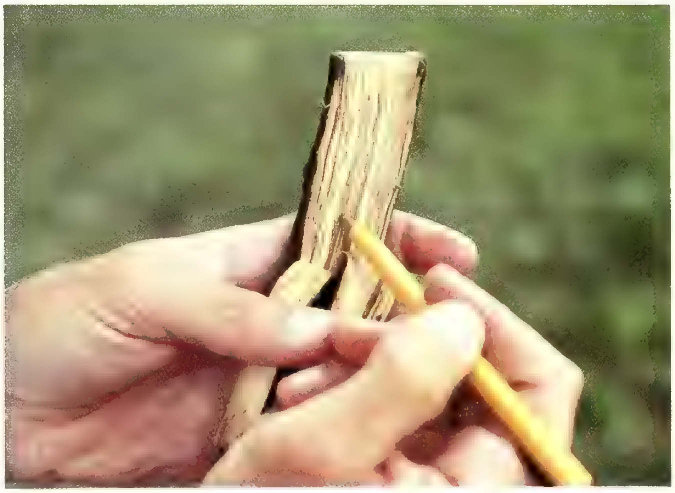


Figure 41-3. Brown streaking in the wood indicates presence of *Ceratocystis ulmi* in host vascular tissue.

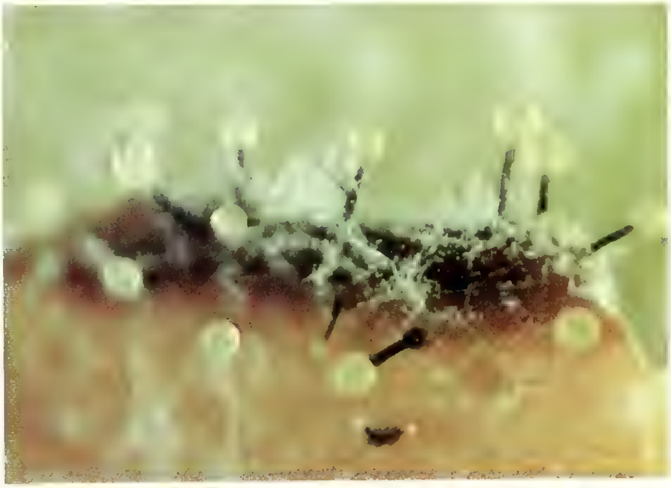


Figure 41-4. Pesotum (Graphium) stage of *C. ulmi* produced on wood chips plated on an agar medium.

42. Dothiorella Wilt of Elm

Joseph M. Krupinsky and Robert L. James

Dothiorella ulmi causes Dothiorella wilt (Cephalosporium wilt, native elm wilt, elm dieback) of elm species. Dothiorella wilt is a vascular disease whose symptoms are frequently confused with those of Dutch elm disease or Verticillium wilt.

Hosts and Distribution

This disease has been widely reported since 1929 from Oklahoma north to North Dakota and into Canada. The disease is present in native stands and planted elms throughout North America. It is commonly found on American elm, and occasionally on slippery, Siberian, and cedar elms. The fungus is often isolated from samples being processed for detection of the Dutch elm disease pathogen. Resistance to this pathogen has not been found in elms.

Symptoms and Signs

Symptoms of Dothiorella wilt include wilting, curling, and yellowing of foliage, followed by defoliation and gradual dieback of branches (figs. 42–1, 42–2). Internally, there is a brown, diffuse streaking of the vascular tissue (fig. 42–3). This discoloration is evident before external symptoms appear. Flat cankers may develop on small branches. Diseased bark turns reddish brown, then darkens and shrinks. Small black fungal fruiting structures (pycnidia) may develop on the dead bark associated with cankers. Dead branches are usually invaded by secondary fungi such as *Phoma*, *Cytospora*, and *Sphaeropsis*; close examination is required to identify pycnidia of *D. ulmi*.

Symptoms are similar to those of Dutch elm disease and Verticillium wilt; the diseases cannot be distinguished without making isolations. Isolation methods include placing infected wood chips on agar media and incubating them so the fungus can be recovered for identification.

Pycnidia of *D. ulmi* are black, and occur in groups of 2 to 12, occasionally single, and 63–160 μm in diameter. Conidia are 1-celled, hyaline, elongate, rounded at both ends, straight or slightly curved, and 2.9–5.4 by 0.5–1.0 μm (av. 3.6–0.8 μm). Cultures of *D. ulmi* growing on malt or potato-dextrose media are variable in color and growth rate, but are usually brown and slow-growing with a filamentous margin. The *Cephalosporium* stage of the fungus develops in culture. On potato-dextrose agar, *Cephalosporium* is characterized by a well-developed, hyaline, septate mycelium. The simple conidiophores are straight, mostly unbranched, and vary in length from 0.7 to 20.0 μm (av. 5.6 μm). The conidia are hyaline, unicellular, elliptic, and 4.5 by 1.9 μm. Conidia are held in place by a mucilaginous substance in which 50 to 80 spores may be massed into a globular head.

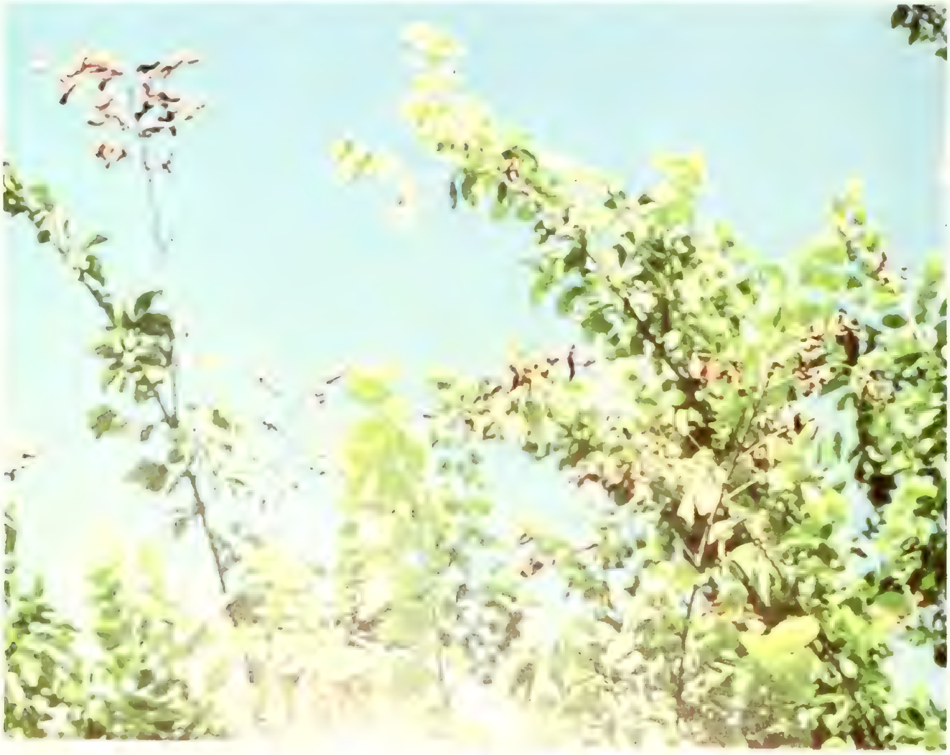


Figure 42-1. Wilting of elm branches infected with *Dothiorella ulmi*.

Disease Cycle

The fungus overwinters in infected tissue. In the spring, fungal spores exude from the pycnidia and are dispersed by wind, rain, or insects. The fungus invades through wounds in leaves and tender shoots, and then spreads to other parts of the tree through the vascular system. Affected branches develop dieback, cankers, and associated pycnidia.

Damage

The disease may progress slowly. Two to 4 years may be required to kill a large tree, whereas seedlings are often killed during one season. Some diseased trees may be symptomless for several years before symptoms reappear. The amount of damage caused by this disease in the Great Plains is unknown.

Control

Prune infected branches several feet below the last visible discoloration in the wood. Infected branches should be burned or buried in a landfill. Several prunings may be necessary. High-value trees should be kept vigorous by watering and fertilizing as needed.

Selected References

Goss, R. W.; Frink, Paul Raymond. Cephalosporium wilt and die-back of the white elm. Res. Bull. 70. Lincoln: University of Nebraska Agricultural Experiment Station; 1934. 24 p.

May, Curtis; Gravatt, G. F. Two native vascular diseases of eastern hardwoods. Tree Pest Leaflet 19. Washington, DC: U.S. Department of Agriculture, Division of Forest Pathology; 1937. 4 p.

Riffle, Jerry W. Dothiorella canker. In: Stipes, R. Jay; Campana, Richard J., eds. Compendium of elm diseases. St. Paul, MN: American Phytopathological Society; 1981: 39.

Schreiber, Lawrence R.; Townsend, Alden M. Dothiorella wilt. In: Stipes, R. Jay; Campana, Richard J., eds. Compendium of elm diseases. St. Paul, MN: American Phytopathological Society; 1981: 24–25.

Verrall, A. F.; May, Curtis. A new species of *Dothiorella* causing die-back of elm. Mycologia. 29: 321–324; 1937.

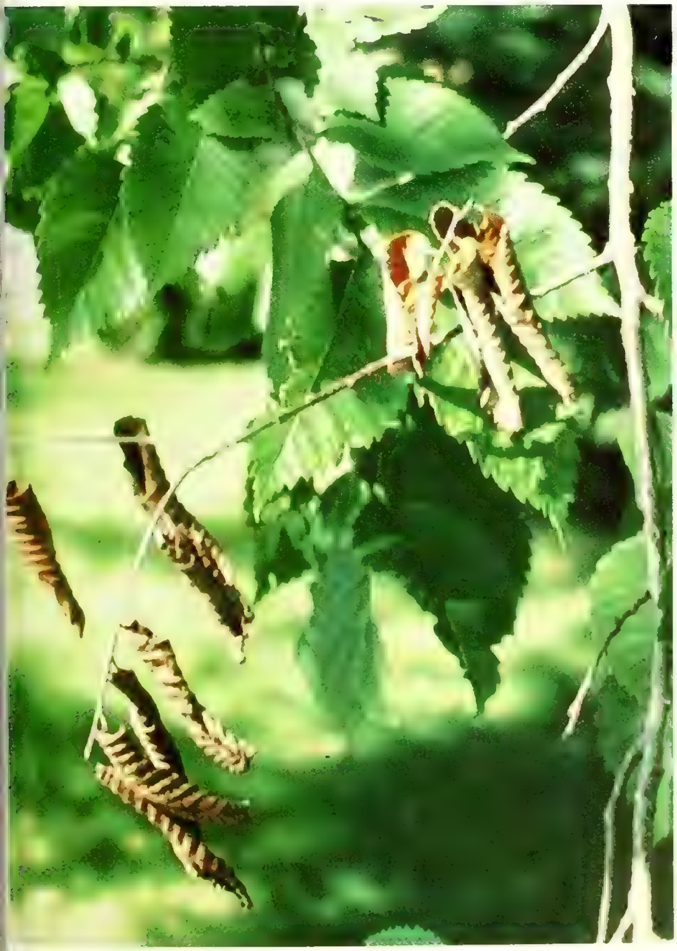


Figure 42-2. Close-up of wilting foliage affected by *Dothiorella*, showing curling of leaves.

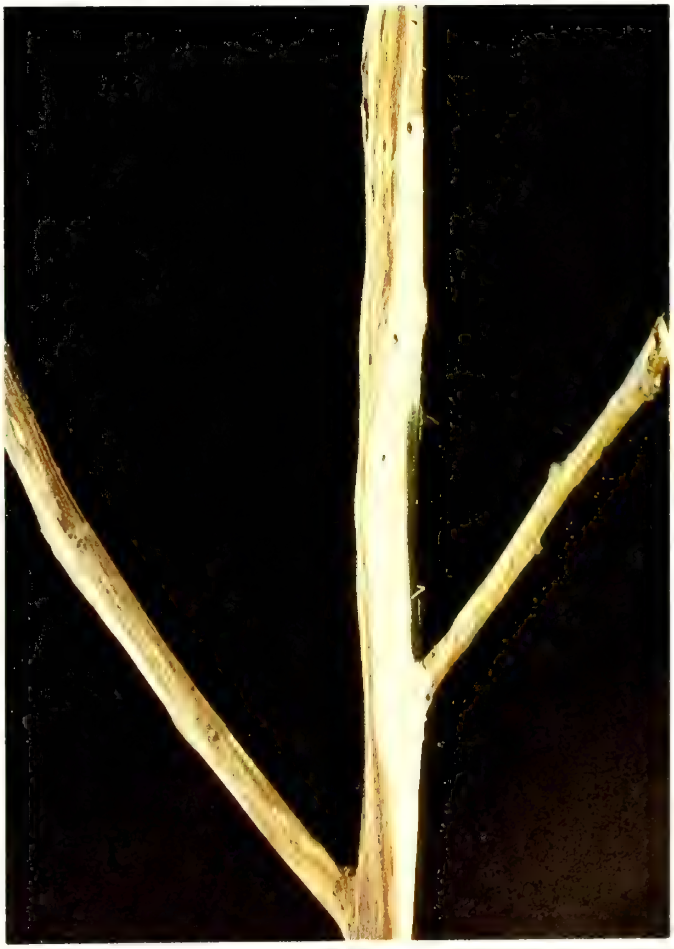


Figure 42-3. Brown streaks in wood of elm with Dothiorella wilt.

43. Elm Yellows

Wayne A. Sinclair and David S. Wysong

Elms native to the United States are subject to a systemic, lethal disease called elm yellows, formerly phloem necrosis. The disease is caused by a mycoplasmalike organism (MLO) which is transmitted by leafhoppers and other homopteran insects. Because the pathogen has not yet been cultivated apart from plant or insect hosts, it has not been fully described or named. Epidemics of elm yellows from the late 1800's to the present have killed tens of thousands of elm shade trees as well as wild elms.

Hosts and Distribution

Natural infections are known only in winged elm, American elm, cedar elm, red or slippery elm, September elm, and *Ulmus rubra* x *U. pumila* hybrids. The hybrids show various symptoms but remain alive, while trees of the above species die when affected by yellows. Siberian elm seems immune.

The disease now occurs in 22 States from Kansas, Nebraska, and Oklahoma eastward, and from Minnesota to Mississippi. It is spreading slowly, and by 1983 had reached approximately 99° west.

Symptoms and Signs

Foliar symptoms (figs. 43–1, 43–2) usually develop between mid-June and mid-September. In American elm these include drooping, yellowing, and premature casting. The sequence takes only a few weeks. All branches usually show symptoms at once, but occasionally leaves yellow first on just one branch. Bright yellow leaves are sometimes interspersed with green ones, but more often all leaves discolor. Twigs and branches dry out after the leaves fall. Trees sometimes wilt and die rapidly, most often in late spring to mid-summer. Shrivelled brown leaves remain on trees for several weeks.

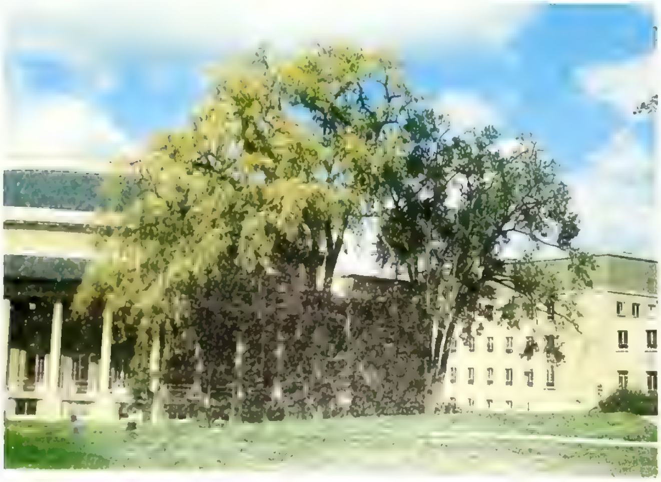


Figure 43-1. [illegible]

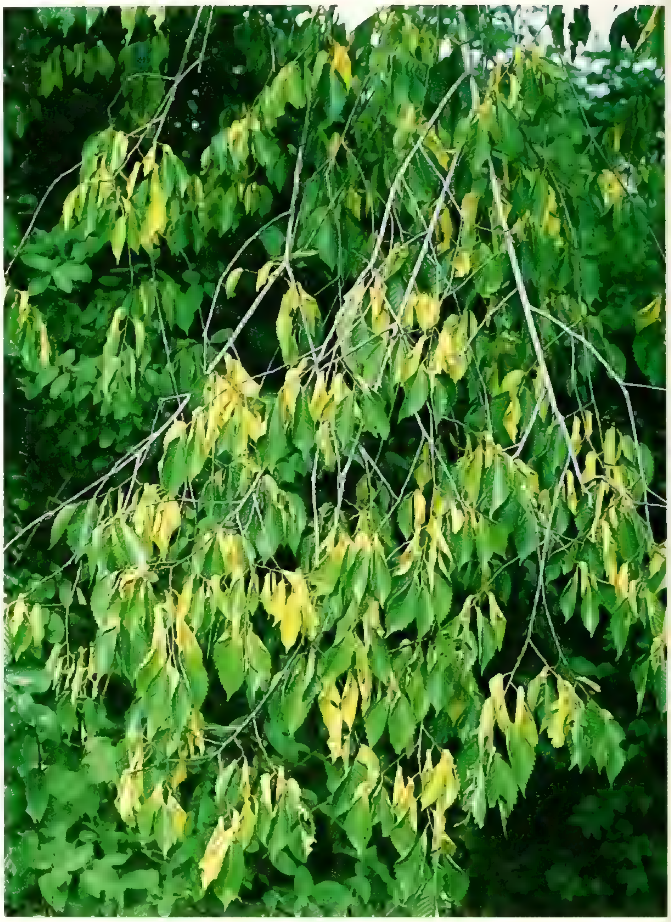


Figure 43-2. Drooping yellow and green leaves.

By the time leaves turn yellow, roots and the inner bark at the base of the tree may be dying or dead. Fine roots die first. As large roots and the trunk become involved, the innermost bark and the cambial zone change color from normal light cream to light yellow, then tan sometimes flecked with dark brown (figs. 43–3, 43–4), and finally dark brown. The remainder of the bark then dies. The phloem on upper branches usually does not discolor. On exposure to air, the inner phloem and cambial region of infected elms turn brown much more rapidly than do comparable tissues of healthy elms.

Infected phloem produces methyl salicylate (oil of wintergreen), which can often be smelled at the surface of freshly exposed, moist inner bark. If indistinct, the odor can be concentrated by enclosing a phloem sam-

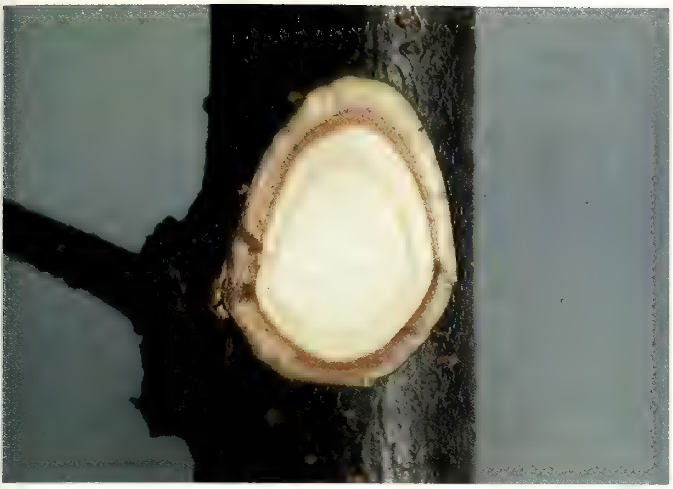


Figure 43-3. Discolored inner phloem and cambial region seen in slant cut into small stem.

ple in a small container for a few minutes. Wintergreen odor cannot be detected after the leaves turn brown or the bark dies.

Symptoms in red elm fit the same general pattern except that, in the majority of infected trees, witches'-brooms form during the final season before death, and no wintergreen odor is produced. The brooms are ordinarily only a few cm long (fig. 43–5), but occasionally become much larger. Infected red elms show discolored phloem inconsistently, and this sometimes includes elliptical pockets of dark brown, degenerated tissue a few mm long. Leaves and bark of red elms killed by yellows produce a characteristic odor that reminds some of caramel, others of maple syrup. This odor does not occur in red elms dying from other causes.

Disease Cycle

The elm yellows agent is probably spread by several different insects, including leafhoppers and spittlebugs. The yellows agent also spreads among closely spaced trees of the same species via root grafts.

The causal mycoplasma-like organisms are found in phloem sieve tubes throughout the plant. They can be observed with electron microscopy but generally not with a light microscope.

Few if any elms show yellows in the year of inoculation; symptom development requires at least 3 months in very small trees, and 9 months or more in large ones. The yellows agent thus overwinters in its plant hosts. Most transmissions are thought to occur during the last half of the growing season, and a typical disease cycle lasts 1 to 2 years.

Elms can show yellows symptoms for several years before death, but this is rare. Most American elms die within 1-year and red elms within 2 years after foliar symptoms appear. Recovery is unknown.

Damage

Outbreaks of elm yellows are usually localized, but sometimes spread at rates of 3 to 5 miles per year. Spot outbreaks presumably develop after long-distance transport of vectors by wind. The disease can be endemic for many years between outbreaks in a given locale. When an outbreak begins, however, it characteristically continues until few elms remain in the locality. Trees of all sizes die.

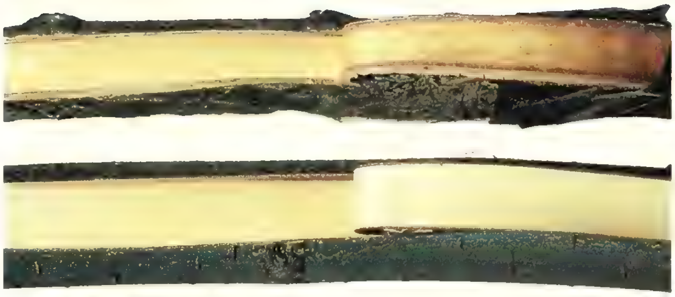
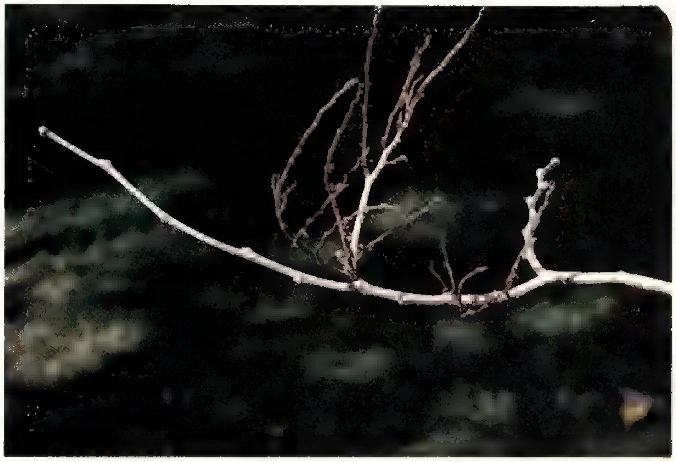


Figure 43-4. Bark peeled from main stems of saplings shows yellowish inner phloem flecked with brown (upper), compared to normal, healthy trees (lower).

Figure 43-5. Branch of defoliated red elm bears small brooms.



Control

No practical controls are available for elm yellows in susceptible trees. Resistant trees are the only available approach. Natural infections of European and Asiatic elm species are unknown. Therefore, pending more detailed information, exotic elms adapted to the Great Plains may be planted without fear of loss to elm yellows.

Selected References

Sinclair, Wayne A. Elm yellows. In: Stipes, R. Jay; Campana, Richard J., eds. Compendium of elm diseases. St. Paul, MN: American Phytopathological Society; 1981: 25–31.

Swingle, Roger U. Phloem necrosis, a virus disease of the American elm. Circular 640. Washington, DC: U.S. Department of Agriculture; 1942. 8 p.

44. Verticillium Wilt of Maple, Catalpa, and Elm

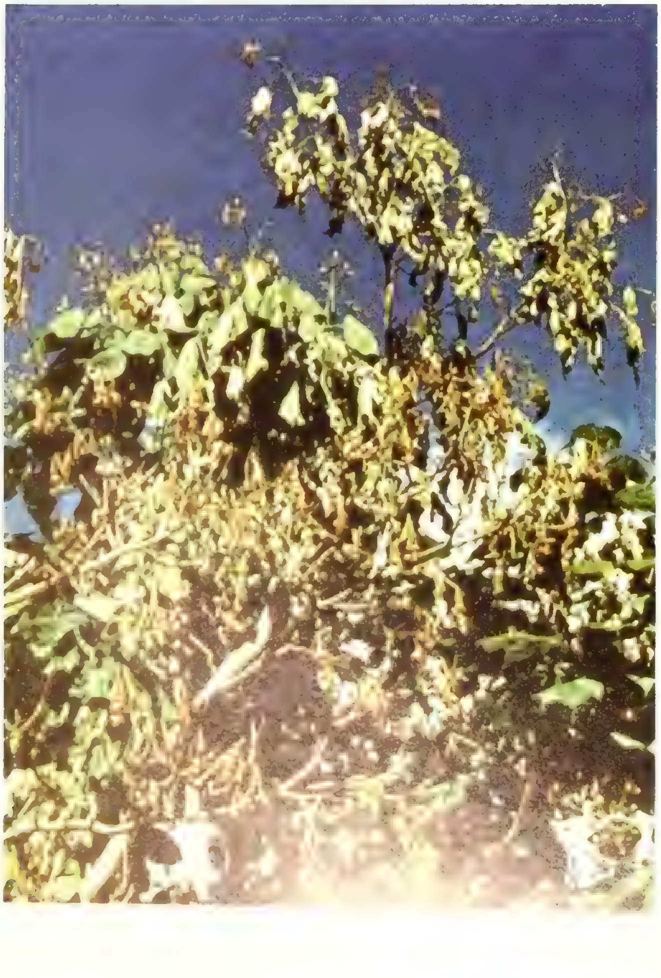
David S. Wysong and Mark O. Harrell

Two closely related (perhaps identical) species of fungi belonging in the genus *Verticillium* are associated with Verticillium wilt: *V. albo-atrum* and *V. dalhiae*. It is sufficient for our purpose to consider the two as one in relationship to the disease caused.

Hosts and Distribution

Verticillium wilt affects more than 300 kinds of plants, including food and fiber crops, annual and perennial ornamentals, and landscape trees. The disease may occur in forest stands, but it is far more destructive in landscape plantings. Valuable ornamental trees may be killed, or damaged to the extent that they must be replaced. The disease occurs in every country in the world, and in every State in the United States.

Figure 44-1. Foliage wilt of catalpa infected by *Verticillium albo-atrum*.



Symptoms and Signs

General symptoms of Verticillium wilt in trees are similar to those caused by other wilt diseases, but specific symptoms are often dependent on the host. Rapid wilting and dying of leaves on individual limbs is typical in many tree species. In maple, elm, and catalpa a general yellowing precedes wilting (fig. 44–1); in elm partial defoliation may also occur. Trees may first show leaf symptoms as early as March or as late as November. When early wilting of leaves on individual branches goes unnoticed, sudden wilting of the entire crown may be the first symptom seen by the homeowner. Other external symptoms include reduction in current twig growth, dieback of twigs, and sparseness in crowns. Some trees such as maple may have elongated areas of dead bark on branches and trunks. Elms are considered tolerant to infection, and commonly show stunting caused by chronically reduced growth. In these cases, trees may decline slowly over several years, and may eventually die.

Vascular streaking is another symptom of Verticillium-infected trees. In branches with advanced stages of wilt, the sapwood will discolor in the form of bands or streaks that run with the grain of the wood (fig. 44–2). Discoloration occurs most frequently in the springwood of the current season's growth. In trees that wilt in early summer, the discoloration may not be noticeable when the branch is examined in cross section. However, it is usually conspicuous as fine streaks on the surface of the sapwood when the bark is carefully peeled from a wilted branch. In branch cross sections, the discoloration appears as a series of dots in a single wood ring; in some cases, the dots are so abundant that the entire wood ring appears discolored (fig. 44–3).

In severely wilted trees the discoloration in the sapwood may be abundant and extend to the tips of wilted branches; in others the discoloration may be limited to the trunk sapwood or it may extend only a few inches into the basal portions of wilted branches. Diseased wood is light to dark brown in many species of trees, including elms. In maple it is light to dark green, and in catalpa, purplish pink changing to bluish brown upon drying. Ash wood shows no streaking, even when severely infected.

Disease Cycle

Verticillium is a soil-borne fungus that, once established in host tissue, is restricted to the water-conducting vessels. Invasion often occurs through the root system. The fungus usually enters through wounds, although vounds are not necessary for infection. After coloniza- ion, the fungus can spread throughout the plant either oy spores transported with the sap stream or by direct extension of vegetative mycelium. Optimum temperature or growth of the fungus in plants is 65° – 72°F. If the olant is killed by *Verticillium*, the pathogen survives in he roots and trunk and can remain viable for several years.

In addition to asexual spores (conidia), the fungus also produces resting structures called microsclerotia, which allow the fungus to persist in the soil for long periods separate from its parasitized host. Conidia do not sur- vive for more than a few weeks in soils. Microsclerotia are produced readily at 70° – 85°F and are most abun- dant in the top 12 inches of soil of all types.

The dispersal of resting structures is a major deterrent o control of Verticillium wilt. One of the most impor- ant means of dispersal is by movement of soil, such as when trees are transplanted from nurseries to landscape sites. Microsclerotia are carried in root balls or on bare roots of infected trees, and contaminate the soil where he trees are planted. In nursery fields the microsclerotia can be spread by normal tillage operations. They may also spread in soil that adheres to equipment used in an nfested field.

)amage

Damage due to infection by *Verticillium* is variable, and lepends upon age of the host and species affected. It is iot uncommon for trees with trunk diameters of 1 to 2 nches to be killed within 1 year of infection. Older trees nay live several to many years following infection, but ypically they gradually deteriorate over time. The lisease has a greater impact on nursery seedlings and rees in landscape situations than on trees in forest tands.

:ontrol

The best method of controlling Verticillium wilt in rees and shrubs is prevention. Avoid planting suscepti- ble trees in soil where other plants are known to have lied from the disease. Fertilization may help prevent the lisease in landscape planting, or in some cases, help af- ected trees recover. Wilt severity is increased by "high itrogen" fertilizers. "Balanced" fertilizers such as 0-10-10 (N-P-K) are recommended. Infected trees should lso be watered every 10 – 14 days with the equivalent f 2 inches of rainfall. Low soil moisture sometimes auses the wilt symptoms to be more severe.

Dead branches showing severe wilt symptoms should e removed or pruned back to wood showing no vascular treaking. Sterilize pruning tools with rubbing alcohol r sodium hypochlorite after each use while pruning to void transmitting the fungus. Pruning diseased bran- hes will not eliminate the fungus from the trunk or oots, however. All dead branches or dead wood should e burned, not buried. A note of caution on pruning: ranches showing slight wilting of leaves should not be removed immediately; they may recover in response to water and fertilizer treatments.

Because *Verticillium* is a vascular wilt pathogen, commonly used fungicides applied to topical surfaces are not effective. A systemic fungicide (one that is absorbed and translocated within the host plant) is necessary to reach the site where the pathogen is active. Mertect (thiabendazole) and Benlate (benomyl) gave some degree of protection to Russian-olive and sugar maple seedlings when applied as a soil drench two weeks after soil infestation. In the same study, foliar applications of these fungicides did not control the disease. The conclusion of this study was that chemical control of Verticillium wilt, even with systemic fungicides, is not practical when treating established trees.

Selected References

Carter, J. Cedric. Diseases of Midwest trees. Urbana: University of Illinois Press; 1979. 168 p.

Himelick, Eugene B.; Neely, Dan. Verticillium wilt. In: Stipes, R. Jay; Campana, Richard J., eds. St. Paul, MN: Compendium of elm diseases. American Phytopathological Society; 1981: 22–24.

Smith, Larry D. Verticillium wilt of landscape trees. Journal of Arboriculture. 5(9): 193–197; 1979.

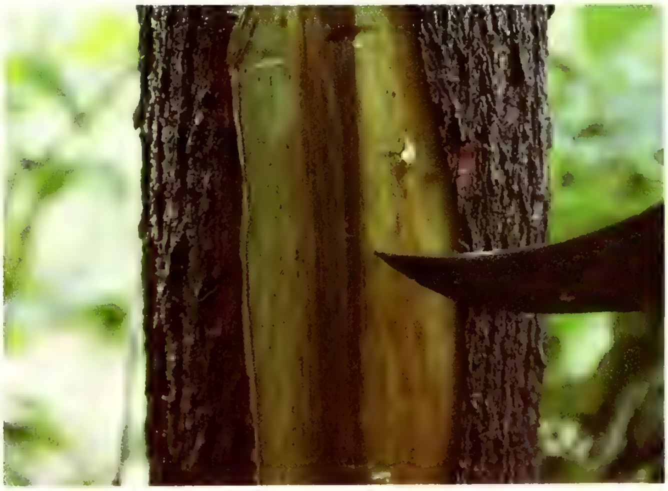
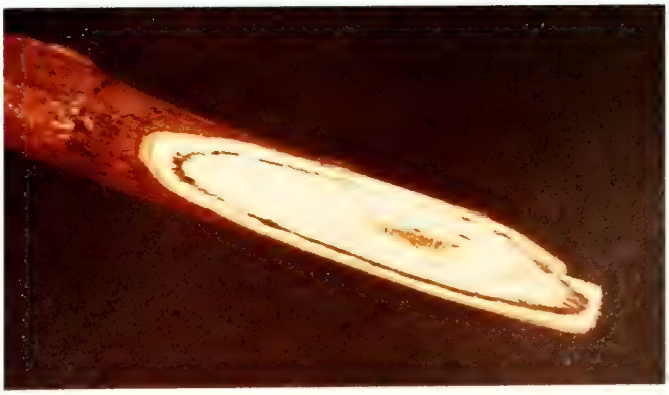


Figure 44-2. Bark removed from maple stem to reveal vascular discoloration caused by *V. albo-atrum*.

Figure 44-3. Brown streaking of elm infected with *V. albo-atrum*.



45. Oak Wilt

David S. Wysong and Edward M. Sharon

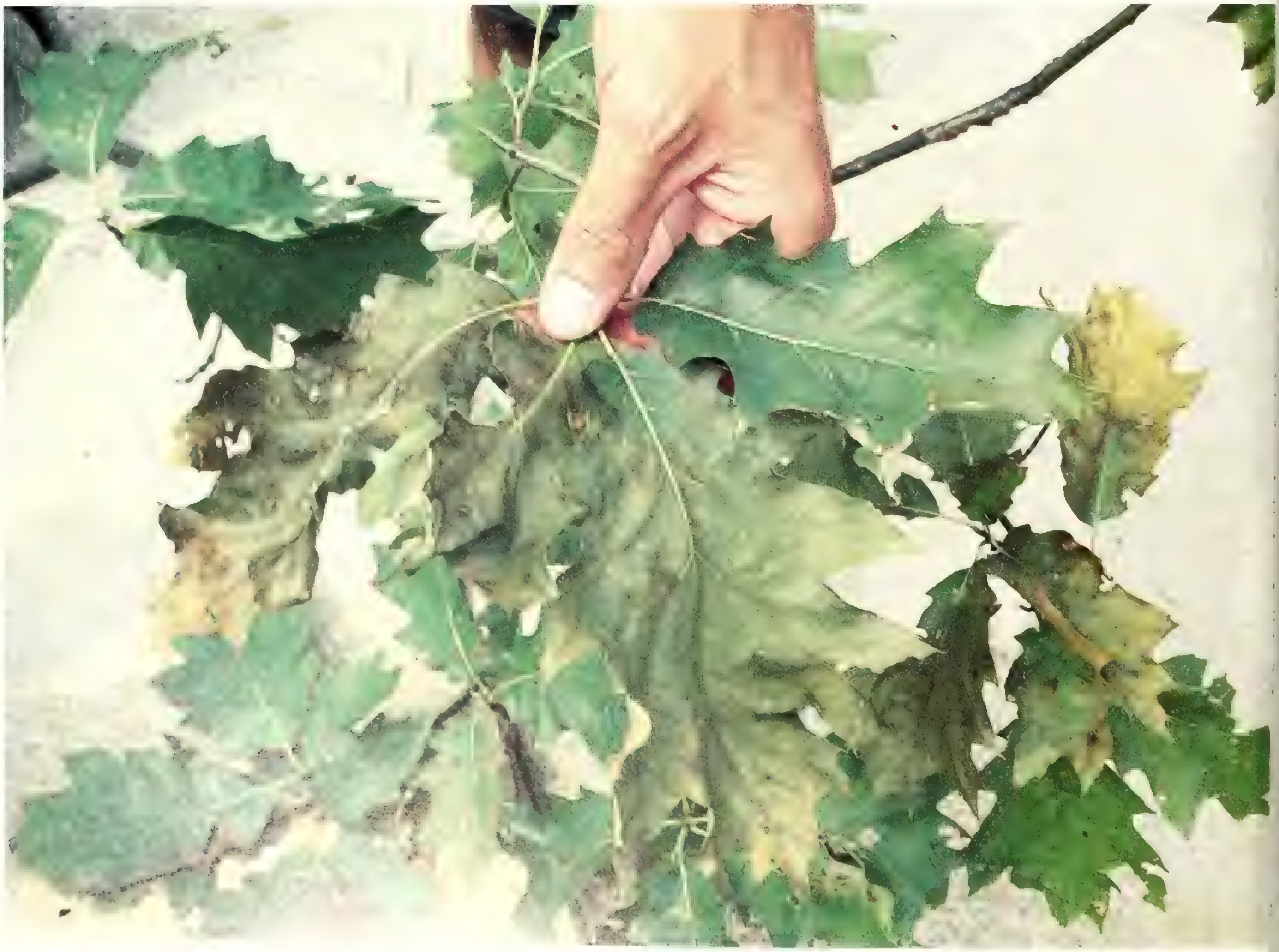
The oak wilt pathogen, *Ceratocystis fagacearum*, is believed to be native to the United States and to have originated in the Upper Mississippi Valley. Disease survey records as early as 1912 describe mortality in oak stands in Minnesota and Wisconsin similar to mortality now known to be caused by the oak wilt fungus. Mortality was attributed to several factors, such as drought or Armillaria root rot, until 1940 when the causal agent was identified as a vascular fungus.

Hosts and Distribution

Oak wilt ranges from Minnesota east to Pennsylvania, south to South Carolina and Tennessee, west to central Texas, and north through Kansas and Nebraska. The disease has been present in Nebraska for over 20 years, but it has been confirmed in only seven counties that border the Missouri River.

Known hosts of the oak wilt fungus include 36 species of oak and six species closely related to oak. All species of oak tested have proven susceptible to the fungus either by natural infection or by artificial inoculation. Species of the red oak group (black, northern red, pin, and scarlet) are more susceptible than are species of the white oak group (bur, post, and white). The six closely related species include Chinese, American, and Spanish chestnut, Allegheny and bush chinkapin, and tanbark-oak.

Figure 45-1. Typical bronzing symptoms on outer portions of leaves of red oak.



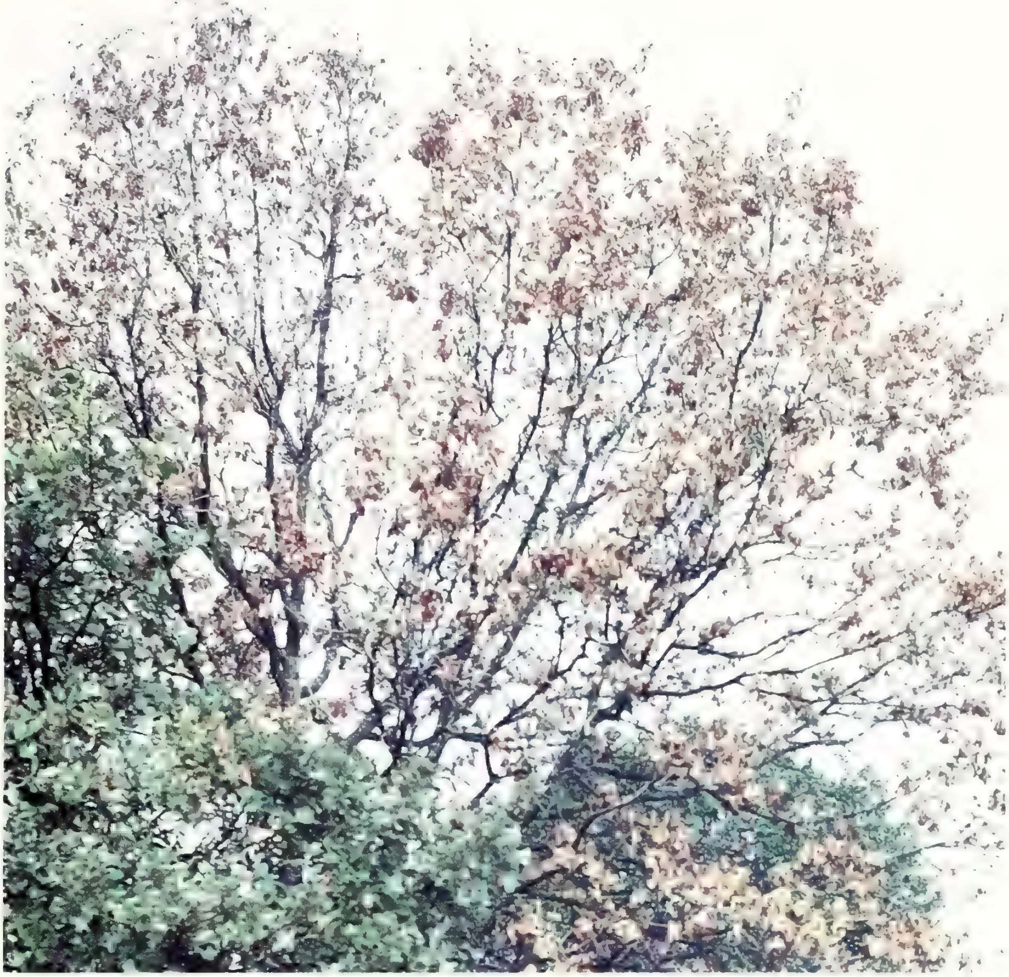


Figure 45-2. Foliage of entire crown of red oak wilted within a few weeks after appearance of initial symptoms.

Symptoms and Signs

Foliage symptoms of oak wilt occur from early June until leaf coloration begins in the fall. Symptoms in the red oak group are slightly different from those in the white oak group.

Early foliage symptoms in the red oak group include wilting, bronzing, and premature defoliation at the branch tips in the upper tree crown. Wilt symptoms rapidly progress down through the crown. Wilted leaves turn dull green, bronze, or tan beginning at the outer portions of the leaf. The base of the leaf and the portion around the main vein are the last to change color (fig. 45–1). Foliage of affected trees commonly wilts within a few weeks after first symptoms appear (fig. 45–2). Brown to black discoloration develops in vascular tissues in the outer sapwood where the tree produces tyloses and gums (fig. 45–3). Red oaks do not recover once infected. Trees infected late in the growing season may produce some leaves on the lower branches the following spring, but these soon wither and die.

Early symptoms in the white oak group are characterized by a wilt of foliage of individual branches in the crown. Leaves may turn yellow, but necrosis is usually limited to the margins of the blade. Affected leaves normally remain attached, and their coloration is similar to normal fall coloration (fig. 45–4). The eventual death of individual branches results in a stag-headed appearance of the crown over a period of several years. Some trees in this group of oaks may die within 2–4 years or longer after infection, but one third to one half of the infected trees may recover and grow normally.

Mycelial masses, or mats, of the fungus may form under the bark within several months after death of the infected tree (fig. 45–5). The fungus mats, which vary in size from one to four inches in length, raise and crack the bark as they enlarge. The black and gray fungus mats give off a fruit-like odor that is very attractive to insects. While the mats are common on infected trees in the red oak group, they are rarely produced on infected white oaks.

Disease Cycle

Oak wilt is caused by the fungus *Ceratocystis fagacearum*, which grows in the functional vessels of the sapwood. The tree responds to infection by producing [illegible] ion bodies restrict the [illegible] disease is strictly a vascular wilt.

By the time symptoms become apparent in the crown of an infected red oak, the fungus is present in the conducting vessels throughout the tree. The fungus in the branches dies a few weeks after the tree dies; the fungus remains alive for several months to a year in the trunk and root system. The fungus produces spores in fungal mats that develop under, and eventually rupture the bark of, recently killed trees. Several insects, particularly oak bark and sap-feeding beetles, are attracted to the fungal mats because of the fermenting odor. As the beetles crawl over these mats, spores of the fungus adhere to their bodies. The beetles fly to other oak trees, feed on the sap flow from fresh wounds, and thereby spread the fungus to these trees. Squirrels and birds may also be potential vectors of the fungus.

Insect transmission of the fungus among trees in the white oak group is very limited, because fungal mats are rarely produced on infected white oaks.

Root grafts are an important means of fungus transmission between trees. Roots of oaks form natural grafts. Once the fungus enters a tree it can spread to nearby trees through these grafts. This method of transmission has been observed in both red and white oak groups.

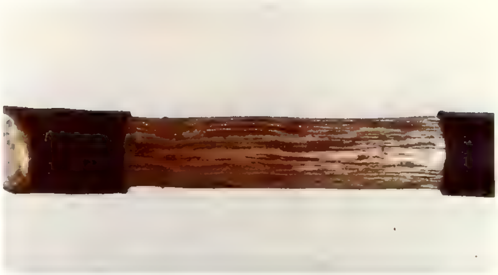
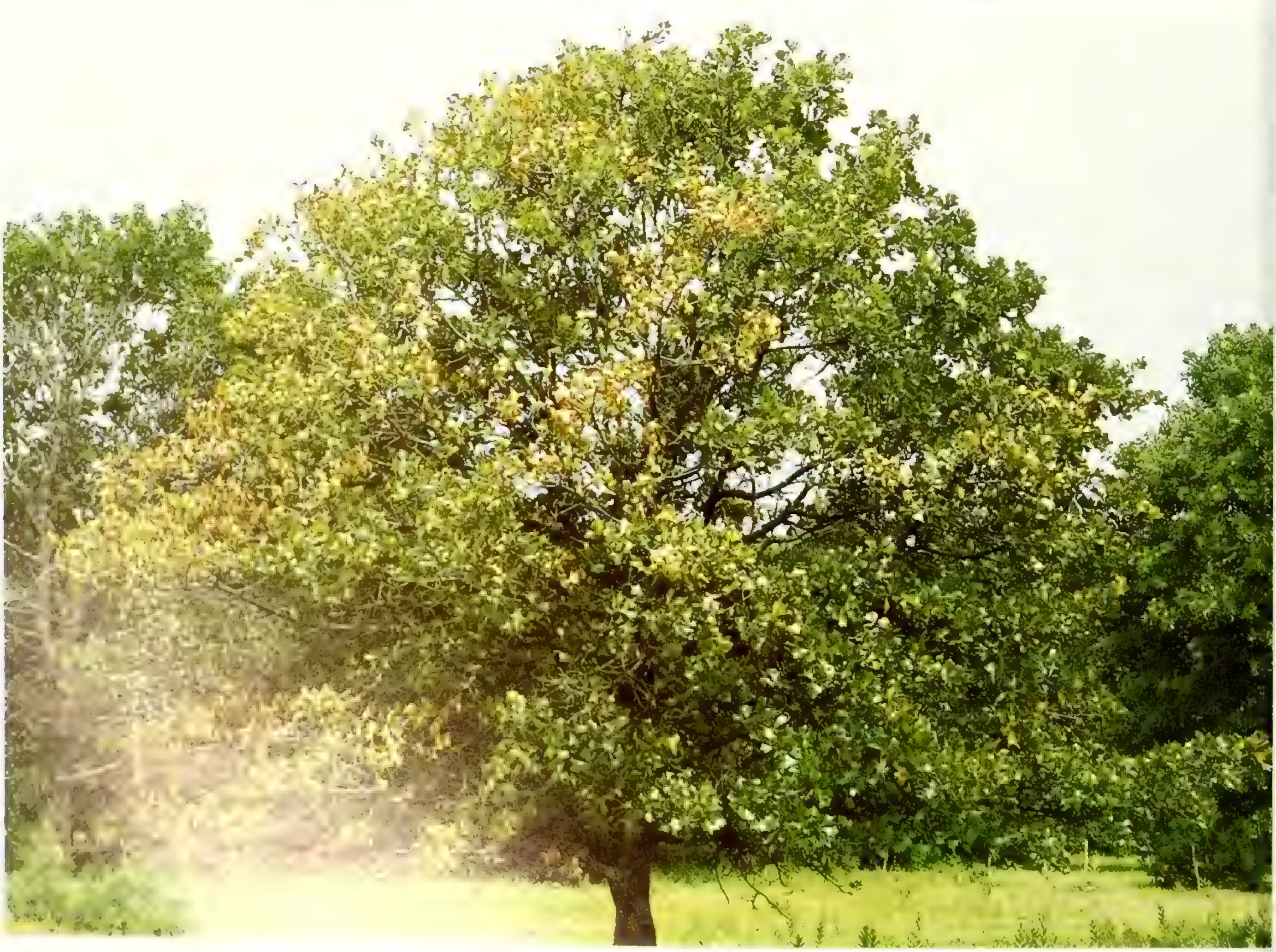


Figure 45-3. Brown discoloration of sapwood of infected stem.

Figure 45-4. Foliage symptoms on trees of white oak group. Leaves remain attached and their discoloration is similar to normal fall coloration.



Damage

Oak wilt continues to threaten oak forests and landscape plantings throughout their native range. Fortunately, catastrophic losses to the disease, feared by many in its early history, have not materialized. Still, thousands of oaks succumb to oak wilt annually, primarily in forest stands in Wisconsin, Minnesota, and Iowa. A number of States (Pennsylvania, West Virginia, Maryland, Kentucky, Tennessee, and North Carolina) implemented extensive oak wilt control programs in the 1950's and 1960's. Appraisal of these programs suggests that damage from oak wilt would have been much higher in the absence of such efforts, and therefore were justified.

Control

There is no known way of saving infected oaks, at least not red oaks. Control must be aimed at halting the spread of the fungus to healthy trees by (1) preventing root graft transmission, and (2) reducing fungal mat production on recently killed trees. Insect control is impractical.

Over 90 percent of diseased trees probably become infected through root grafts. Spread through such unions can be prevented by mechanically trenching around infected trees after first symptoms develop. A trench 3 feet deep and several inches wide between diseased and healthy trees immediately disrupts root grafts between these adjacent trees. The trench can be refilled because new root grafts will not form between the dead or dying tree and nearby healthy trees.

An alternative method of disrupting root grafts involves the use of SMDC (sodium N-methyldithiocarbamate), sold under various trade names as Vapam, or Trimaton. This fumigant kills the roots in a narrow strip and prevents the fungus from reaching healthy trees. Holes are dug 15 to 18 inches deep and an inch or two in diameter, spaced 6 inches to a foot apart, along a line midway between the diseased tree and adjacent healthy trees. One part of SMDC is mixed with three parts of water, and the diluted solution is poured into each hole. The holes must be closed immediately after application. Some temporary injury may occur in the healthy tree, particularly if the chemical barrier is closer than 10–15 feet from it, because of chemical uptake and limited root kill. Soil texture, temperature, and moisture influence the rate of uptake and effectiveness of treatment.

The second control technique is aimed at preventing spore formation on diseased trees. Spores are produced for only a brief period after the tree dies. The fungus cannot be isolated from the above-ground parts of dead trees when the moisture content of the wood is less than 20 percent. Therefore, any treatment that hastens the drying of wood tissue will tend to reduce sporulation. Deep mechanical girdling of the trunk soon after the disease is diagnosed will hasten drying of the wood and prevent mat formation. Experiments with chemical poisons, such as pressure-injected cacodylic acid, have demonstrated effective root kill and hastened drying.

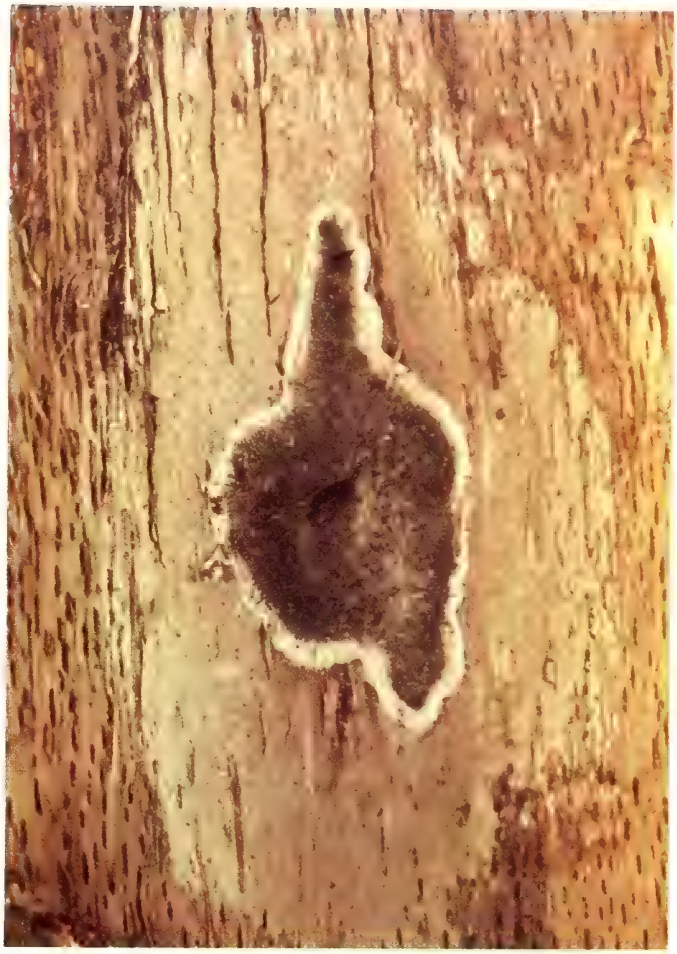


Figure 45-5. Gray mycelial mat of oak wilt fungus. The mat develops under the bark of dead trees.

Finally, infected trees should be cut down and destroyed. They may be burned, buried, or processed into chips for mulching purposes. Members of the white oak group can be used at any time, while red oaks should only be used when they are beyond the stage of producing or harboring spores. If there is potential for sporulation, firewood cut from infected trees should have bark removed or be covered with 4 mil polyethylene until used. Logs from freshly cut timber may be fumigated with methyl bromide under plastic cover for 3 days. Salvaged timber can be milled for lumber, but waste slabs and wood should be chipped, burned, or buried.

Selected References

Appel, D. N.; Fox, T.; Drees, C. Frost. The occurrence of oak wilt in Texas. (Abstract). Phytopathology. 73: 833; 1983.

French, D. W.; Stienstra, Ward C. Oak wilt disease. Extension Folder 310. St. Paul: University of Minnesota; 1975. 6 p.

Himelick, E. B.; Fox, Howard W. Experimental studies on control of oak wilt disease. Illinois Natural History Survey Bulletin 680. 1961. 48 p.

Ostrofsky, William D.; Wysong, David S. Oak wilt. Forest Pests of Nebraska Leaflet 8. Lincoln: University of Nebraska; 1977. 2 p.

46. Mimosa Wilt

Mark W. Andrews

The mimosa or silk tree, a native of eastern Asia, is widely grown as an ornamental and has become naturalized in the southeastern United States and in the southern Great Plains. The tree is valued for rapid growth, graceful foliage, colorful flowers, and capacity to thrive in unfavorable soil conditions. Mimosa wilt, caused by *Fusarium oxysporum* f. sp. *perniciosum*, is a destructive vascular wilt disease of this ornamental.

Hosts and Distribution

Mimosa wilt was first observed in North Carolina in 1953, and since has been found from New York to Florida and into Mississippi and Louisiana.

In inoculation tests, *Albizia julibrissin*, *A. lophantha*, *A. kalkora*, and *A. procera* were susceptible to the causal fungus; *A. thorelii* and *A. pudica* were resistant. Seedlings of native leguminous species *Cercis canadensis*, *Gleditsia triacanthos*, and *Robinia pseudoacacia* were found to be resistant to the pathogen.

Symptoms and Signs

The first external symptom is wilting of the leaves. The leaves then become dry and shrivelled, usually remaining green but sometimes yellow. The leaves fall from the tree soon after they dry (fig. 46–1). The defoliated parts then die; usually the entire tree is dead within 1 year

Figure 46-1. Mimosa tree exhibiting foliar wilt and dieback symptoms.

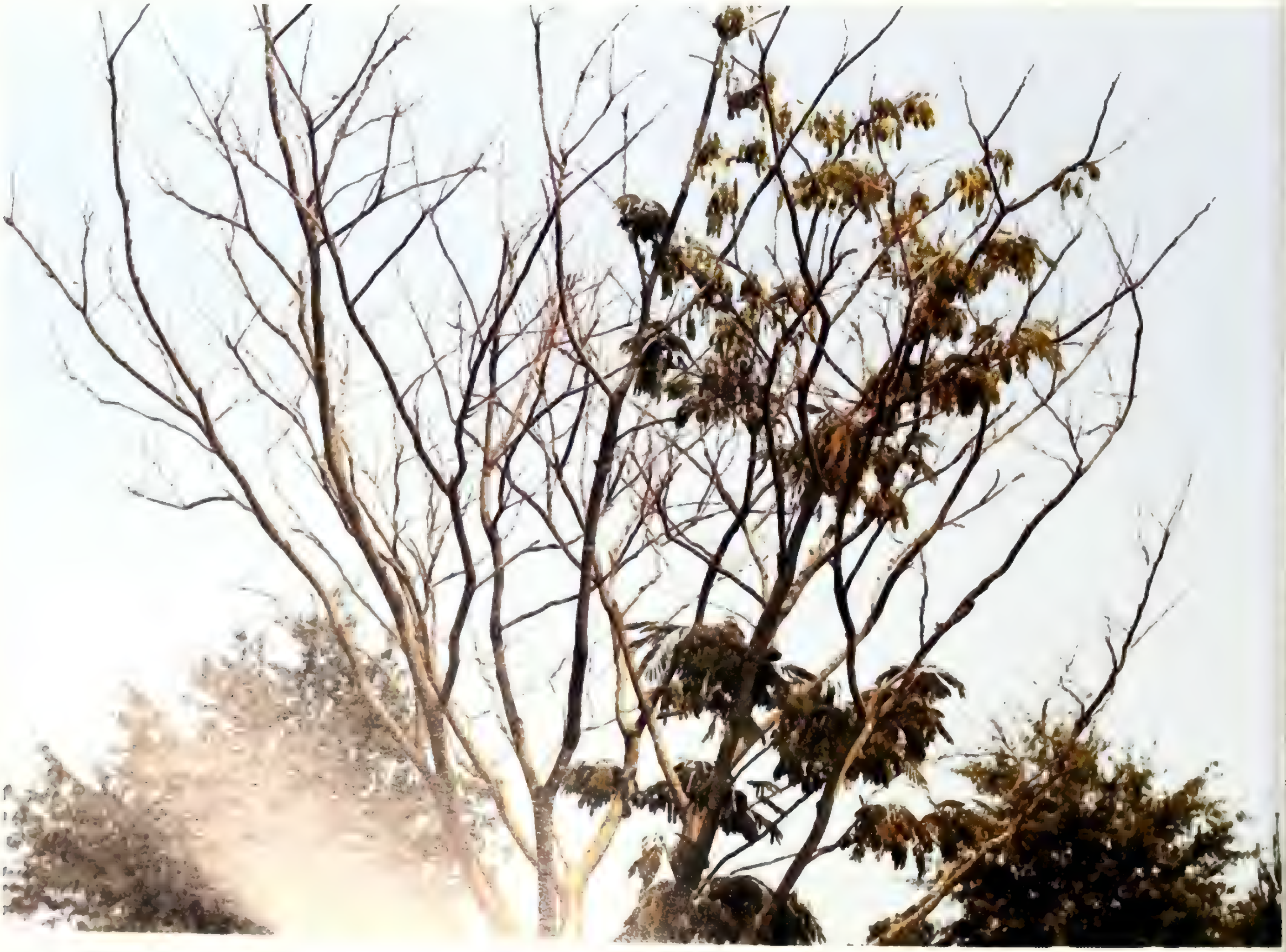
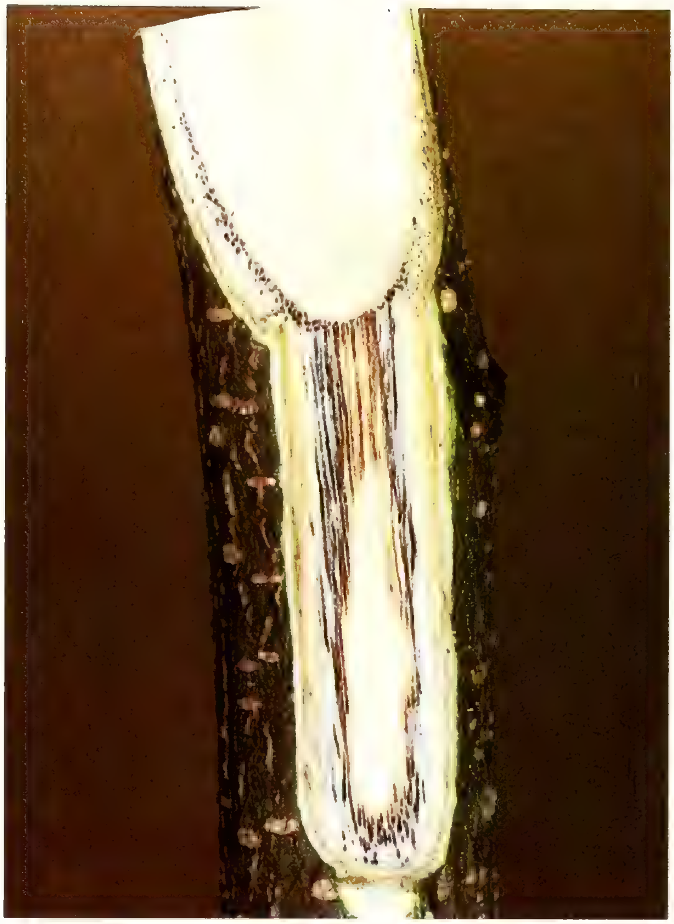


Figure 46-2. Vascular discoloration indicative of mimosa wilt.



from the time the first wilting is apparent. In Louisiana, trees frequently defoliate and die within 1-month of the first visible symptoms. Cross sections of wilted branches show a reddish-brown to black discoloration in the outer sapwood, especially in the springwood vessels of the last annual ring (fig. 46-2). Discoloration is most intense in the roots, and diminishes in intensity in the stem and branches.

Disease Cycle

F. oxysporum f. sp. *perniciosum* is a soilborne organism that enters host roots either through wounds, or directly through root hairs or the epidermis of small roots. The production and release of microconidia into the sapstream then results in rapid colonization of aboveground parts. The fungus causes the development of gum-like substances in vasicentric parenchyma cells. These substances are exuded into the vessels, thereby plugging them and causing the diagnostic vascular discoloration. The vascular discoloration symptoms of mimosa wilt differ from other vascular wilt diseases in that tyloses are not observed in vessel elements.

Once systemic invasion has occurred, wilt symptoms develop rapidly and kill the tree. The pathogen moves laterally from vessel elements into the cambium and phloem through ray parenchyma. The pathogen emerges from the host through lenticels in the bark, where sporodochia develop and produce masses of macroconidia. During this time the roots decay and the fungus is released into the soil.

Control

There is no effective control for this disease. Toole and Hepting developed, by selection and propagation, lines of mimosa resistant to the disease. Two cultivars, "Tyron" and "Charlotte", were released to nurseries in 1949; however, resistance of these cultivars was reported as ineffective after 15 years.

The systemic fungicides benomyl and thiabendazole were shown to control mimosa wilt, but in most cases both fungicides failed to eradicate the fungus within mimosa. Thus their practical use may be limited to periodic preventive applications.

Where the disease has appeared, it is recommended that mimosa be replaced with other species because mimosa can no longer be successfully grown there.

Selected References

Attabhanyo, Anusorn; Holcomb, G. E. Control of Fusarium wilt of mimosa with systemic fungicides. Plant Disease Reporter. 60: 56–59; 1976.

Gill, D. L. Wilt of mimosa wilt-resistant cultivars. Plant Disease Reporter. 48: 648; 1964.

Phipps, P. M.; Stipes, R. J. Control of Fusarium wilt of mimosa with benomyl and thiabendazole. Phytopathology. 65: 504–506; 1975.

Phipps, P. M.; Stipes, R. J. Histopathology of mimosa infected with *Fusarium oxysporum* f. sp. *perniciosum*. Phytopathology. 66: 839–843; 1976.

Toole, E. Richard; Hepting, George H. Selection and propagation of Albizzia for resistance to Fusarium wilt. Phytopathology. 39: 63–70; 1949.

47. Phymatotrichum Root Rot

Glenn W. Peterson and Charles Maier

Phymatotrichum root rot is a major disease of taprooted plants in certain areas of the southwestern United States.

Hosts and Distribution

The fungus *Phymatotrichum omnivorum* has a wide host range that includes most of the species used in Great Plains tree plantings. It affects several tree species in parts of Arizona, Oklahoma, and Texas, where it is particularly damaging to cotton (fig. 47–1).

Symptoms and Signs

Diseased seedlings seldom show pronounced advanced indications but die suddenly, with a typical darkening and wilting of the leaves. Older trees may at first show a reduction in growth and vigor. The leaves may become yellow to bronze and either gradually drop off, giving the crown a thin appearance (cottonwood), or they may remain attached, become dark, dry, curl up, and cling abnormally long to the branches (Russian-olive).

Infected roots commonly are rotted and the epidermis is shrunken and shrivelled. For a few species such as Siberian elm, however, the decay has the characteristics of a wet rot.

Disease Cycle

The fungus has three distinct stages. The sterile mycelium usually appears in the form of buff-colored strands composed of one or more large central hyphae and surrounded by a varying number of small, irregular, thick-walled hyphae. Sclerotia are small, buff, compact bodies ranging up to a grain kernel in size. They are produced from enlargements of the rhizomorphs and, like the rhizomorphs, may remain dormant indefinitely. The spore stage appears on the surface of the soil in the form of a fluffy white mat of mycelia. The mat may be from 1 to 12 inches in diameter. The spore stage generally is considered functionless; infection has not been obtained by inoculations with spore suspensions.

The fungus in any form survives freezing for only a day or two; it is restricted to a region bounded on the north roughly by the latitude of southern Oklahoma.

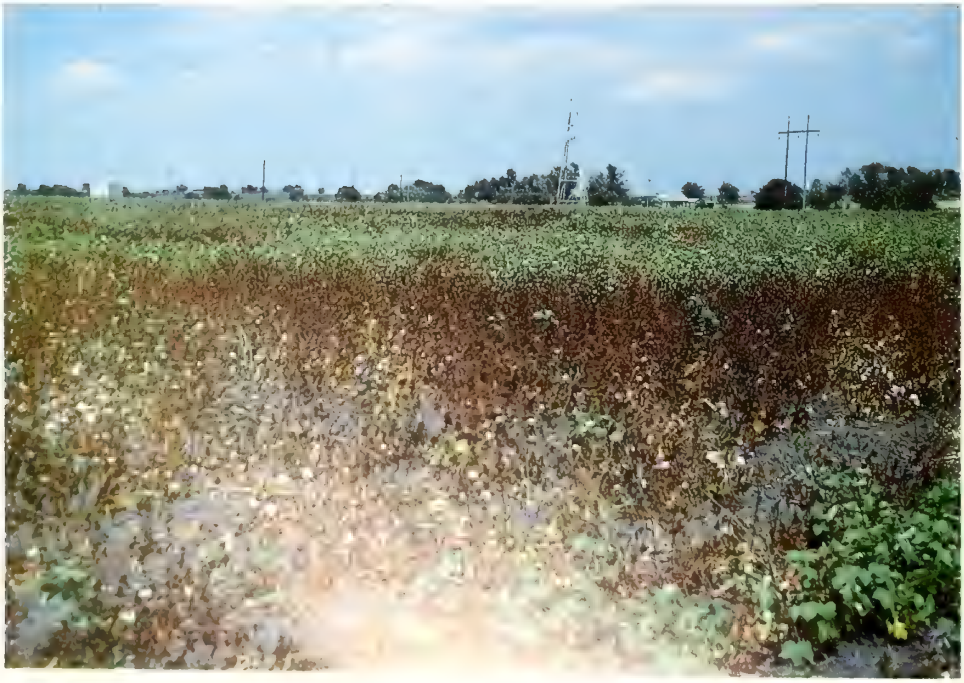


Figure 47-1. Cotton killed by *Phymatotrichum omnivorum*.

Damage

The fungus is commonly found in patches in field crops such as cotton (fig. 47–1). The most damage occurs where trees have been planted in patches where the fungus has infested the soil. Windbreaks established in areas where the patches occur commonly have gaps where the fungus has killed or reduced the vigor of the trees (fig. 47–2).

Control

The impact of this disease can be reduced either by avoiding infested areas when planting trees and/or by planting resistant species. Infested spots could be detected readily when cotton was the crop most commonly planted, but now they are more difficult to detect because resistant crops, such as milo, are widely planted in the Phymatotrichum root rot zones of Oklahoma and Texas. In the early 1940's an evaluation of tree species in some Oklahoma and Texas windbreaks revealed that the following species were resistant: common hackberry, desert-willow, western soapberry, eastern redcedar, and Rocky Mountain juniper. The following species were intermediate in susceptibility: ailanthus, apricot, green ash, northern catalpa, American sycamore, French tamarisk, eastern black walnut, Russian mulberry, and Austrian pine.

Selected References

Peltier, George L. Distribution and prevalence of Ozonium root rot in the shelter-belt zone of Texas. Phytopathology. 27: 145–158; 1937.

Peltier, George L.; Schroeder, F. R.; Wright, Ernest. Distribution and prevalence of Ozonium root rot in the shelterbelt planting area of Oklahoma. Phytopathology. 29: 485–490; 1938.

Taubenhaus, J. J.; Ezekiel, Walter N. A rating of plants with reference to their relative resistance or susceptibility to Phymatotrichum root rot. Bull. 527. College Station: Texas Agricultural Experimental Station; 1936. 52 p.

Wright, Ernest. First progress report on the Phymatotrichum root rot losses in experimental windbreaks of Oklahoma and Texas. Plant Disease Reporter. 24: 13–20; 1940.

Wright, Ernest; Wells, H. R. Tests on the adaptability of trees and shrubs to shelterbelt planting on certain Phymatotrichum root rot infested soils of Oklahoma and Texas. Journal of Forestry. 46: 256–262; 1948.

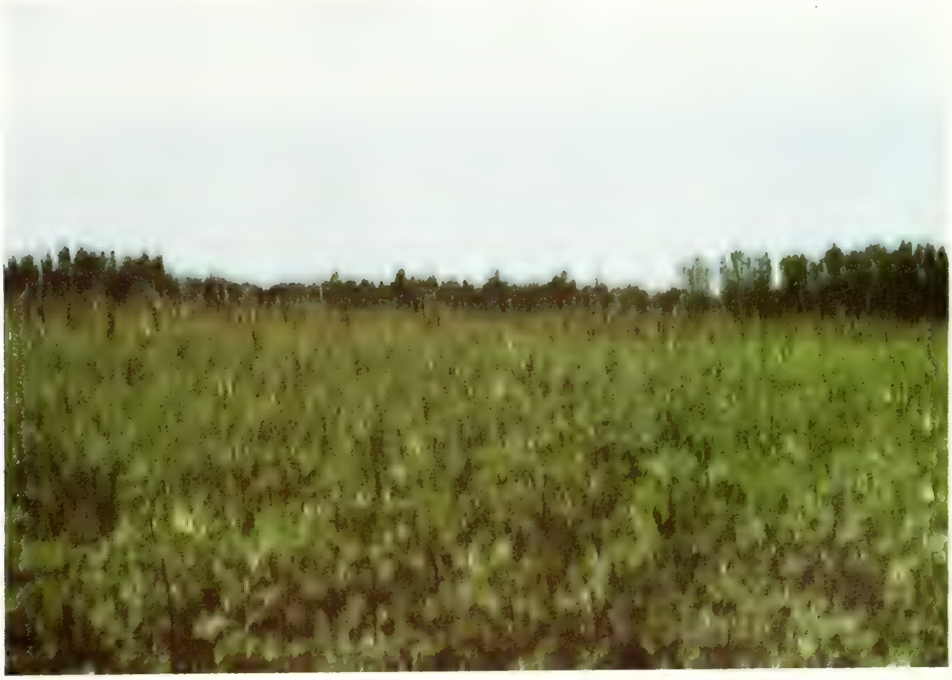


Figure 47-2. Gap in windbreak caused by *P. omnivorum*.

48. Armillaria Root Rot

Lloyd R. Fuller and Robert L. James

Fungi of the genus *Armillaria* are common facultative parasites on more than 600 plant species throughout the world. Root diseases caused by these fungi are responsible for considerable economic damage, especially within plantations, orchards, or vineyards. Many forest conifers and hardwoods, as well as ornamental shrubs and trees, are susceptible to these pathogens.

Hosts and Distribution

Armillaria occurs sporadically throughout the Great Plains. This disease has been reported on over 25 plant species widely planted in landscapes and windbreaks. Some susceptible plants commonly grown in the Great Plains are: boxelder, paper birch, Peking cotoneaster, Tatarian honeysuckle, apple, ponderosa pine, Scots pine, *Quercus* sp., *Prunus* sp., and other members of the rose family (Rosaceae).

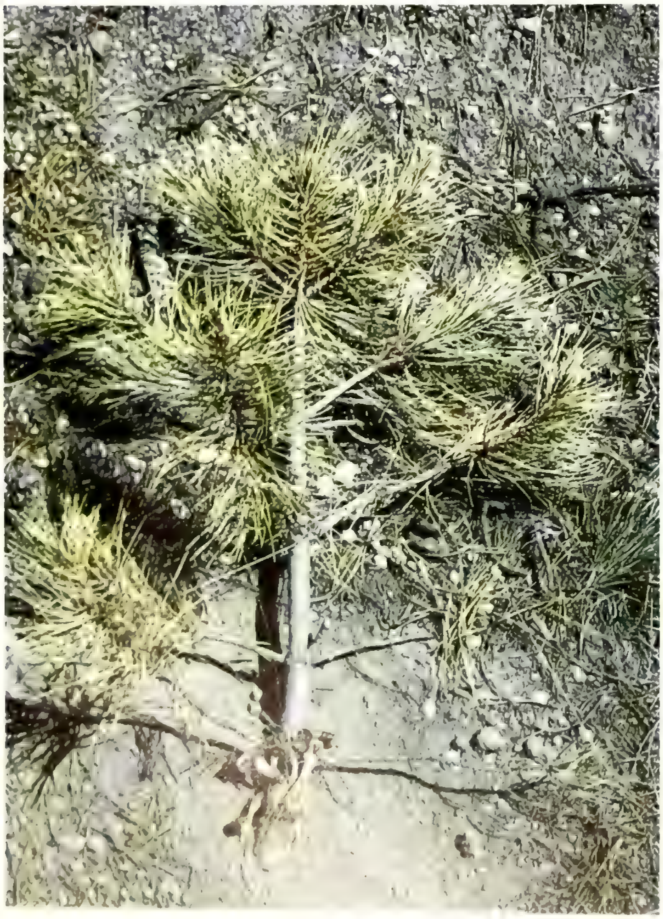


Figure 48-1. Chlorotic foliage [illegible] pine infected with *Arm*[illegible]

Symptoms and Signs

Crown symptoms resemble those of other associated root disorders: reduced height growth, chlorotic foliage, premature foliage drop, dieback, and mortality (fig. 48–1). One or more of these symptoms may be present on a single tree. In addition, hosts infected at the root collar may have external basal resinosis or gummosis.

Armillaria produces a characteristic cream-colored mycelial fan beneath the bark, in the cambial zone, on roots, and at the root collar (fig. 48–2). Rhizomorphs, tough shoestring-like structures made up of hyphae that darken with age, may be found on root surfaces, in adjacent soil, or under loose bark (fig. 48–3).

The most positive signs of *Armillaria* infection are the production of fruiting bodies (fig. 48–4), and their characteristic appearance in culture. *Armillaria* produces an edible, honey-colored mushroom in small to large clusters on living and dead hosts or on soil near buried wood. This mushroom may be present from late summer through fall if moisture is adequate. *Armillaria* mushrooms may be identified by their honey-yellow caps, 1–5 inches across; fine, cinnamon-colored erect hairs over the cap; white spores; and a persistent ring or annulus on the stem. A yellow-capped variant is often observed on hardwoods; a pinkish-brown variant is common on conifers.

Disease Cycle

During favorable late summer or fall weather, *Armillaria* may be a prolific spore producer. However, unlike many other decay fungi, the spores of *Armillaria* rarely initiate disease. *Armillaria* spreads primarily as vegetative mycelium, either by root-to-root contact or by rhizomorphs.

Rhizomorphs can grow considerable distances through the soil, and initiate parasitic infections or saprophytic colonization. When a rhizomorph encounters a host root or root collar, it adheres to the bark surface. Subsequently, by direct pressure and enzymatic action, mycelial strands colonize susceptible host cambium and initiate canker formation. These cankers usually do not progress into lethal infections on healthy, vigorous hosts, but remain quiescent until the host dies naturally, the host vigor decreases significantly, or the host is overwhelmed by numerous parasitic attacks. Successfully attacked hosts usually do not die until infections girdle the root collar cambium.

Following successful parasitic infection, *Armillaria* begins saprophytic colonization of woody tissues beneath infected cambium. In some conifers and hardwoods, *Armillaria* causes wood decay without parasitic cambial infections. In this latter case, *Armillaria* does not appear to kill trees directly, but may predispose them to windthrow.

Damage

Young trees are most likely to be killed by *Armillaria.* Trees 15 to 20 years old are more tolerant to parasitic attacks. *Armillaria,* in general, is not damaging unless hosts are under unusual stress, such as by extended droughts, competition for light and nutrients, insect attacks, or infections by other root pathogens.

Control

Control of root diseases over extensive acreage is seldom possible without considerable effort and cost. Valuable ornamental, shade, and orchard trees, adjacent to infected trees, may be protected by careful removal of infected stump and root material from the soil. Chemicals have been used to sanitize infested soil and wood, but only professional chemical applicators should apply these chemicals near healthy trees.

Planting immune or highly resistant species is the most promising and long lasting approach to Armillaria root rot control. Lists of resistant plants that are well adapted to a locale can be obtained from local extension agents or from the reference by Raabe and McCain (1967).

Make sure planting stock is disease-free. Reduce foliage so crowns are in balance with root systems. Prepare the planting site adequately. In general, to minimize the impact of root diseases, maintain host vigor through adequate and timely applications of water and fertilizers.

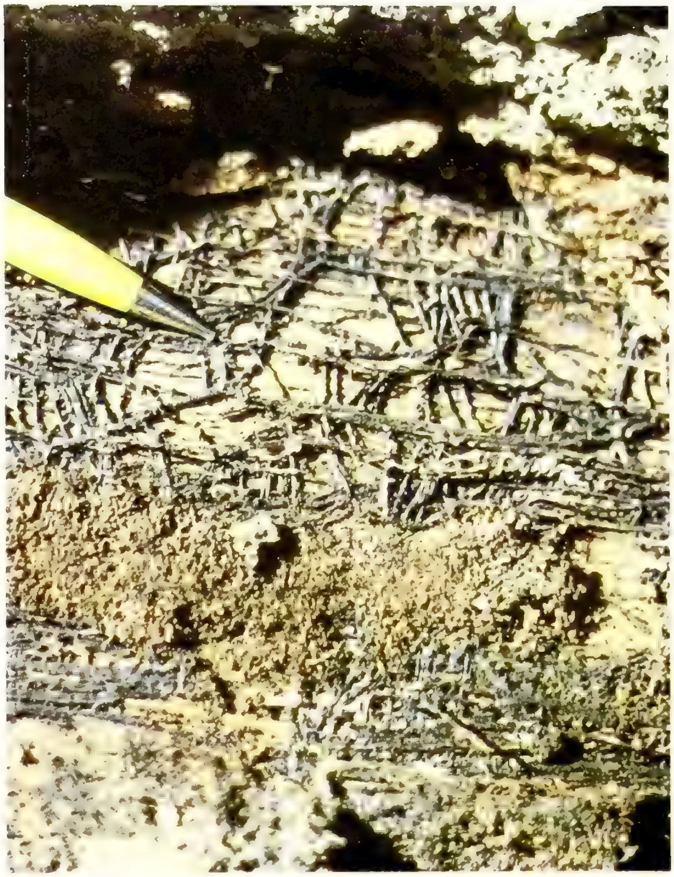


Figure 48-3. Rhizomorphs of *Armillaria* on root surface under bark of host.

Selected References

U. S. Department of Agriculture. Index of plant diseases in the United States. Agric Handb. 165. Washington, DC: U. S. Department of Agriculture; 1960. 531 p.

Miller, Orson K., Jr. Mushrooms of North America. New York: E. P. Dutton & Co.; 1972. 360 p.

Raabe, R. D. Host lists of the root rot fungus *Armillariella mellea.* Hilgardia. 33: 25–88; 1962.

Raabe, R. D.; McCain, A. H. Plants resistant or susceptible to Armillaria root rot. Agricultural Extension Service Bulletin AXT–6. Davis: University of California; 1967. 6 p.

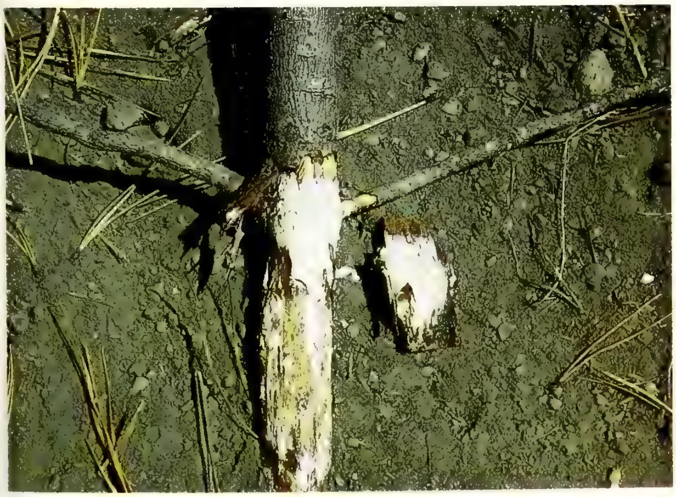


Figure 48-2. Mycelial fans of *Armillaria* in cambial zone of ponderosa pine.

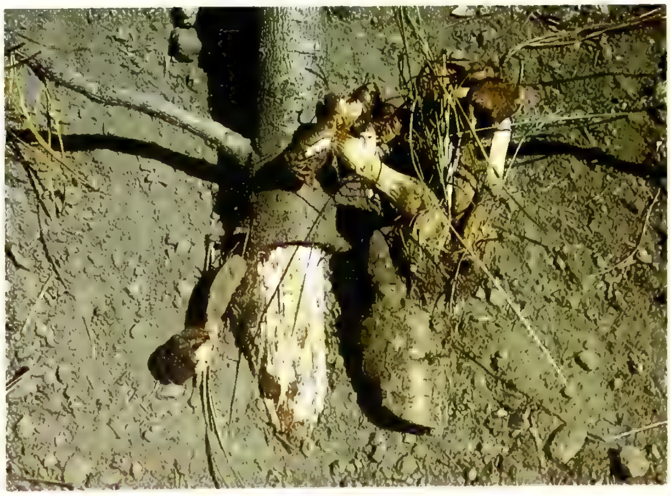


Figure 48-4. Large fruiting bodies of *Armillaria* on bark at root collar of ponderosa pine.

49. Nematodes of Broadleaf Trees

Jerry W. Riffle and Joseph M. Krupinsky

The root zones of trees in nurseries, windbreaks, and natural stands in the Great Plains are inhabited by various microorganisms, including nematodes (fig. 49–1). Nematodes are an important part of the microscopic fauna of these sites; those associated with tree roots include plant-parasitic, mycophagous, bacteriophagous, and predaceous forms. Plant-parasitic nematodes puncture and feed on root cells, and contribute to poor growth and premature decline of trees.

Hosts and Distribution

Cottonwood, green ash, golden willow, and post oak are favored hosts of the dagger nematode, *Xiphinema americanum*. This nematode is widespread and is probably present in most windbreaks on the Great Plains. This association with trees and the high populations in weed-free windbreaks indicate that various other tree species used in such plantings may be hosts for this nematode. Preferring undisturbed sites, dagger nematodes seldom are a problem in nurseries in the Great Plains.

Roots of apple, black locust, black walnut, American elm (fig. 49–2), catalpa, green ash, and multiflora rose have been parasitized by root-knot nematodes, *Meloidogyne* spp., in nurseries in the southern Great Plains. Root-knot nematodes rarely are found on trees in windbreak plantings, however. Apple, black locust, and black walnut also have been parasitized by root-lesion nematodes, *Pratylenchus* spp., in nurseries. Root-lesion nematodes also cause damage to spruces, pines, and junipers (see Article 64). American elm has been damaged by lance (*Hoplolaimus* sp.) and spiral (*Helicotylenchus* spp.) nematodes in nurseries. Other forms that occasionally injure tree roots include stunt (*Tylenchorhynchus* sp.), ring (*Criconemoides* sp.), and stubby-root (*Trichodorus* sp.) nematodes.

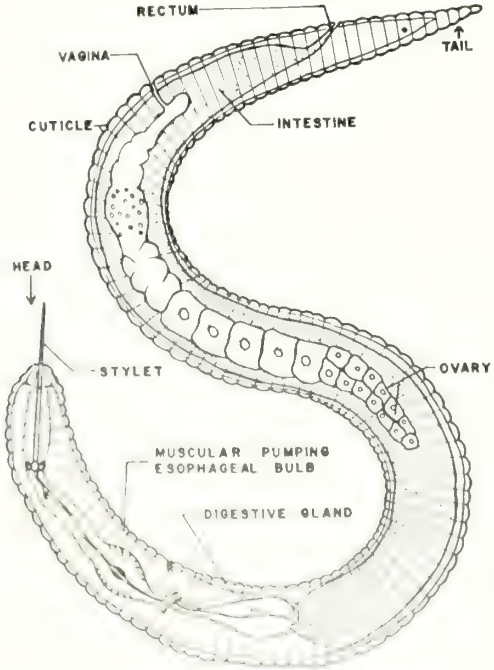


Figure 49–1. The principal parts of a nematode (female).

Symptoms and Signs

Above-ground symptoms on seedlings parasitized by nematodes resemble those on plants lacking an adequate and properly functioning root system. Affected seedlings are characterized by low vigor, stunting, and small, discolored foliage. Below-ground symptoms on feeder roots include root swellings, root proliferation, surface necrosis, lesions, and stubby-root condition resulting from root-tip injury and cessation of growth. Heavily parasitized root systems are discolored and poorly developed. Similar root symptoms occur on established trees.

Diseases caused by nematodes usually cannot be diagnosed by the symptoms described above because other soil-borne pathogens and some environmental factors cause similar symptoms. Various types of injury may be present on roots because of the combined effects of more than one nematode species; for example lesions and stubby-root condition may be present on roots parasitized by both root-lesion and stubby-root nematodes. In addition, nematode injury may increase the incidence of other root diseases by facilitating entry of their causal organisms.

Disease Cycle

The life cycle of plant-parasitic nematodes consists of eggs, four larval stages, and adults. Females lay eggs that hatch into juveniles. These juveniles are similar to adults in appearance and structure in most species; during their growth and development they undergo four molts. After the fourth molt, the individual is an adult. Mature females then lay eggs and the cycle is repeated. Root-knot nematode larvae of both sexes undergo the same development into the last larval stage. At the final molt, the male emerges as a slender eel-shaped adult, while the female becomes pear-shaped or sometimes almost spherical.

There are two general modes of feeding among plant-parasitic nematodes. Ectoparasitic species, such as dagger nematodes, live in the soil and feed externally on succulent root tissue. Through their stylets they inject digestive enzymes into root tissues, making the contents of cells easier to ingest and assimilate. Endoparasites, such as root-knot and root-lesion nematodes, enter and

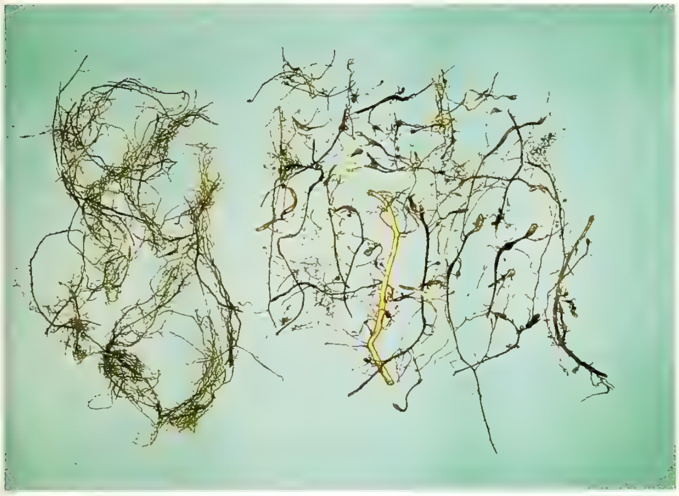


Figure 49-2. Roots of American elm infected with root-knot nematode. Left, noninfested roots; right, infested roots with swollen tips.

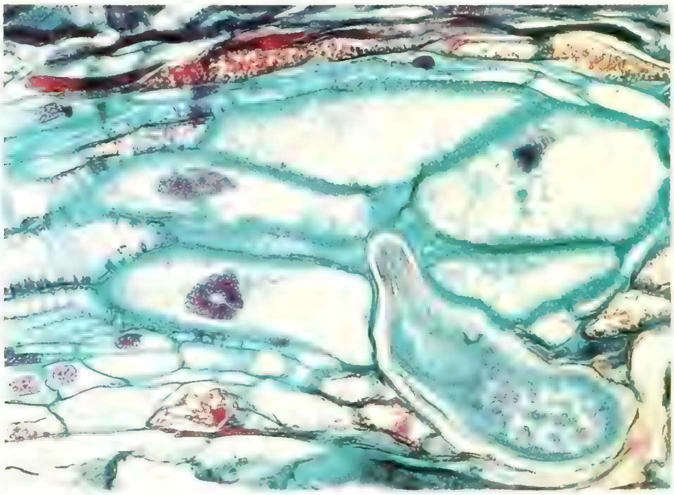


Figure 49-3. Root-knot nematode female (lower right) with giant cells developed in clusters immediately adjacent to its lip region. The sedentary nematodes feed on these giant cells.

complete most of their life cycles inside roots. The secretion injected into surrounding cells by root-knot nematodes modifies the development and maturation of those cells, causing them to form specialized tissue containing "giant cell" (fig. 49–3).

Damage

Endoparasitic nematodes feed on and move through tissues of the root, causing mechanical damage. Root-lesion and lance nematodes may cause substantial mechanical injury to rootlets. Much of the damage by both endo- and ectoparasitic nematodes are due to reaction of root tissues to secretions injected into roots while the nematodes are feeding. The specialized tissue induced by root-knot nematodes disrupts root absorption and translocation of moisture and nutrients. Weakened root systems may result in enhanced winter injury, increased susceptibility to canker pathogens, branch dieback, and premature decline.

Nematodes have caused severe damage to broadleaf seedlings in some Great Plains nurseries and to trees in windbreaks. The extent of injury to seedlings depends upon type of nematode, degree of infestation, and species and age of seedlings. Damage in infested seedbeds usually is first evident in irregularly shaped spots. These spots enlarge and coalesce over a number of years as nematodes multiply and spread throughout the seedbed. Pathogenic fungi often enter roots through wounds made by nematodes, and the resulting disease complex often causes considerably more loss to a seedling crop than would be caused by either acting alone.

Many windbreaks in the northern Great Plains are planted in habitats favorable for dagger nematodes. Native grasses and alfalfa are hosts of this nematode, and trees planted on such sites are exposed immediately to high nematode populations. In these situations premature tree decline is common, and occasionally tree mortality is high 2 or 3 years after planting. Populations as high as 13,300 per pint of soil have been reported around roots of cottonwood in windbreaks in South Dakota.

Control

Plant-parasitic nematodes can be controlled by cultural or chemical methods. Crop rotation with non-host cover crops may be used to reduce populations of certain species. For example, where root-knot nematodes are a problem, rotation with fescue (a non-host) is recommended over soybeans (a host). Summer fallow, accompanied by frequent tilling, will reduce populations of nematodes by starvation and desiccation in areas of low or seasonal rainfall and high soil temperatures.

Preplant soil fumigation provides excellent control of nematodes in nurseries. Volatile, halogenated hydrocarbons such as methyl bromide are widely used. In South Dakota, soil fumigation of windbreak planting sites with 1,3–dichloropropene and related chlorinated C_3 hydrocarbons (1,3-D) increased growth of green ash and golden willow over a 4-year period on land infested initially with low populations of dagger nematodes, but did not affect growth of cottonwood, Siberian peashrub, or honeylocust. Root-knot nematode on hardwood seedlings can be controlled by dipping infected roots in organophosphate nematicides prior to transplanting.

Selected References

Malek, R. B. The dagger nematode, *Xiphinema americanum*, associated with decline of shelterbelt trees in South Dakota. Plant Disease Reporter. 52: 795–798; 1968.

Malek, R. B.; Smolik, J. D. Effect of *Xiphinema americanum* on growth of shelterbelt trees. Plant Disease Reporter. 59: 144–148; 1975.

Thorne, Gerald; Malek, Richard B. Nematodes of the Northern Great Plains. Part 1 Tylenchida (Nemata: Secernentea). Tech. Bull. 31. Brookings: South Dakota Agricultural Experiment Station; 1968. 111 p.

50. Phomopsis Blight of Junipers

Glenn W. Peterson

Phomopsis blight has been a serious problem for more than 75 years in nurseries producing juniper seedlings and grafts (fig. 50–1).

Hosts and Distribution

Phomopsis juniperovora, the fungus causing this disease, is widespread in the Great Plains (fig. 50–2). Losses have been most severe in seedling and transplant beds of eastern redcedar and Rocky Mountain juniper. Other junipers are susceptible, as are some species in the genera *Chamaecyparis*, *Cupressus*, and *Thuja*.

Symptoms and Signs

P. juniperovora initially infects foliage, then spreads to and sometimes kills stem tissues. Newly developing needles are especially susceptible while they are still in the yellowish-green stage; after needles become a normal, deep green, they are no longer susceptible. Small yellow spots appear on young needles of eastern redcedar and Rocky Mountain juniper within 3 to 5 days after infection. The fungus ramifies within infected needles and rapidly invades and girdles young stems. When a side shoot is infected, the fungus progresses to the main stem, which it may girdle if the stem is less than 1 cm in diameter. The portion of the seedling above the girdled area then dies.

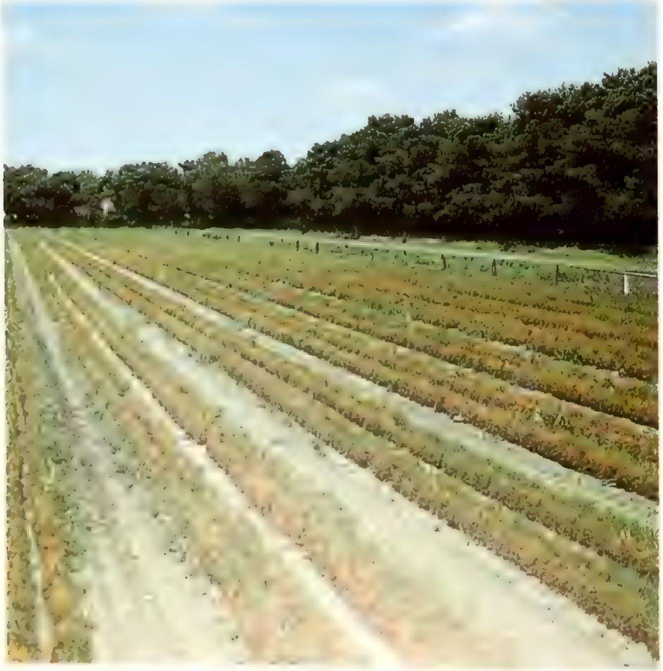


Figure 50-1. Phomopsis [illegible]

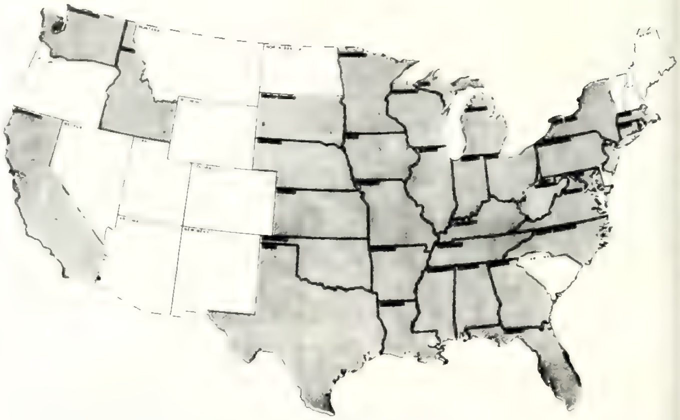


Figure 50-2. States in which *P. juniperovora* is present (gray).

At first, infected tissues turn light green but rapidly change to the characteristic red-brown color of dead shoots, which finally turn ashen gray. Lesions on larger stems frequently develop into cankers, but the stems are not girdled. The fungus does not spread far below the cankers.

Disease Cycle

Spores produced in fruiting bodies (pycnidia) formed on leaves and stems of seedlings infected the previous year are the most important source of inoculum early in the growing season. Pycnidia with viable spores may develop within 3 to 4 weeks after seedlings become infected, but usually are not well developed until infected tissues have dried considerably. Pycnidia are found most commonly on tissues that have turned ashen gray. The pycnidia are embedded at first in needles and stems, but partially erupt through the epidermis (fig. 50–3). Two types of spores (alpha and beta) develop in the same or different pycnidia (fig. 50–4) and are extruded in whitish tendrils. The alpha spores are colorless, one-celled, ellipsoid, contain two oil globules, and commonly are 7.5 to 10 by 2.2 to 2.8 μm; the beta spores are colorless, one-celled, filamentous, slightly curved, and commonly 20.2 to 26.9 by 1 μm. The fungus can produce spores for as long as 2 years in dead parts of infected plants.

Spores are dispersed primarily by rain splash. Infection is caused by alpha-spores; the filamentous beta-spores do not germinate. Only a short period of high humidity is needed for infection to occur; for example, seedlings exposed to 100 percent relative humidity and 75°F for only 7 hours can become infected. Spore germination, germ-tube development, and infection are optimum near 75°F, but disease development is enhanced by higher temperatures (90°F).

Damage

Total loss of first-year seedlings is common in epidemic years if control measures are not used. Losses are particularly high in areas where water tends to stand, and in beds of new seedlings adjacent to infected older seedlings. Some of the worst epidemics occur late in the growing season, when there is a late flush of growth on juniper seedlings.

Survival of even lightly blighted nursery stock is very poor, because new shoots continue to be infected by spores produced on old infected tissues.

When junipers in landscape plantings become infected, they may become unsightly because of numerous dead branch tips (fig. 50–5). Older trees seldom are killed because only small-diameter stems are girdled. For this reason, Phomopsis blight does not cause significant damage in natural stands of junipers.

Control

Because susceptible new foliage and viable fungus spores are present throughout the growing season in juniper seedling beds, protective fungicides need to be applied regularly during this season. Benomyl is the only chemical currently registered for control of Phomopsis blight. This chemical applied at 7- to 10-day intervals, combined with a vigorous schedule of roguing infected seedlings over the same interval, will give excellent control.

Other actions can be taken to reduce losses. Sowing juniper seed adjacent to beds containing juniper stock should be avoided if possible. Poorly drained areas should be avoided because losses are often greater where water tends to stand. If overhead sprinklers are used, seedlings should be irrigated so that water on seedlings dries before nightfall. Because shading frames increase the length of time that moisture remains on foliage, they should not be used unless absolutely necessary. Junipers or other hosts of this fungus should not be used in nursery windbreaks or in landscape plantings on nursery grounds, because they may be a source of inoculum (spores) for nursery stock. Such trees are more likely to be extensively infected if pruning results in development of juvenile foliage.

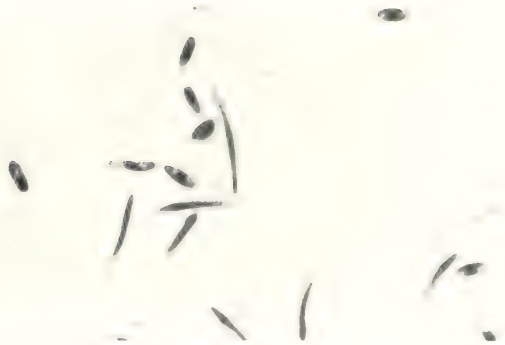


Figure 50-4. Alpha (ellipsoidal) and beta (long) spores of *P. juniperovora*.

Susceptibility to *P. juniperovora* varies considerably among junipers. Research is seeking to determine if there is useable genetic resistance to *P. juniperovora* among and within progenies from select eastern redcedar trees.

Selected References

Otta, J. D. Benomyl and thiophanate methyl control Phomopsis blight of eastern redcedar in a nursery. Plant Disease Reporter. 58: 476–477; 1974.

Peterson, Glenn W. Infection of *Juniperus virginiana* and *J. scopulorum* by *Phomopsis juniperovora*. Phytopathology. 63: 246–251; 1973.

Peterson, Glenn W. Phomopsis blight of junipers. In: Forest nursery diseases in the United States. Agric. Handb. 470. Washington, DC: U.S. Department of Agriculture; 1975: 76–79.

Peterson, Glenn W.; Hodges, C. S. Jr. Phomopsis blight of junipers. Forest Insect and Disease Leaflet 154. Washington, DC: U.S. Department of Agriculture, Forest Service; 1982. 7 p.

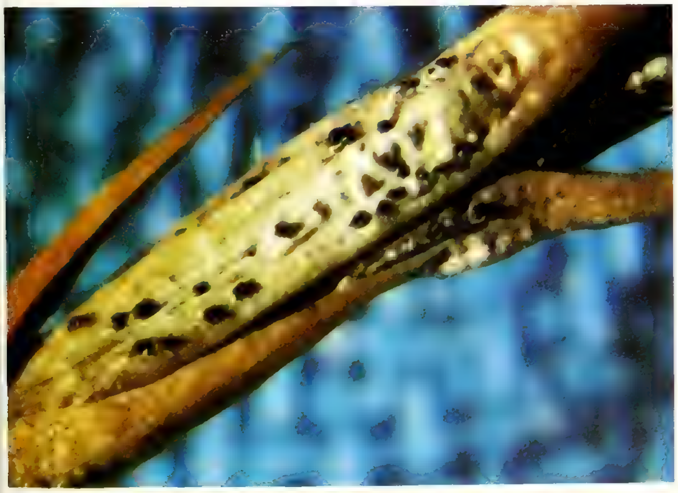


Figure 50-3. Pycnidia on leaves and branches.

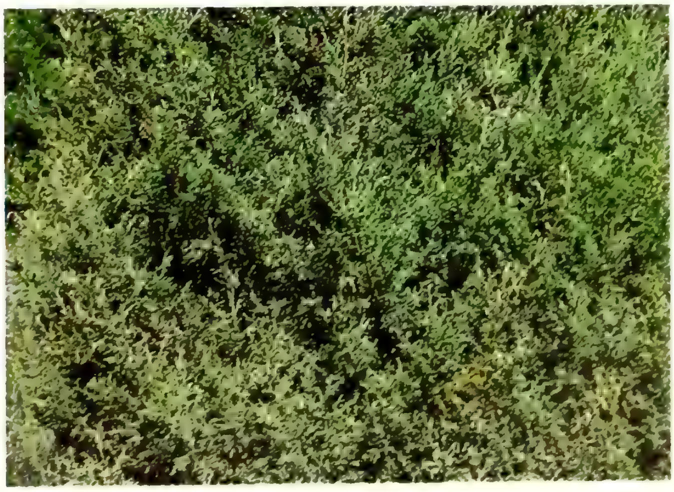


Figure 50-5. Branch tips of 7-year-old *Juniperus virginiana* damaged by *P. juniperovora*.

51. Cercospora Blight of Junipers

Glenn W. Peterson and David S. Wysong

Junipers and other members of the Cupressaceae family are infected by two closely related needle-blighting fungi, *Cercospora sequoiae* and *Cercospora sequoiae* var. *juniperi.*

Hosts and Distribution

In the Great Plains, *C. sequoiae* var. *juniperi* has severely damaged eastern redcedar and Rocky Mountain juniper in well-established windbreaks and other plantings. The distribution of these two fungi in the central United States is shown in figure 51–1.

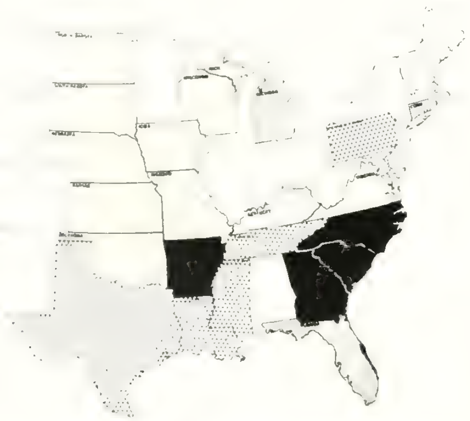


Figure 51-1. Geographic distribution of *Cercospora sequoiae* and *C. sequoiae* var. *juniperi. C. sequoiae* dots; *C. sequoiae* var. *juniperi* gray; both black.

Symptoms and Signs

Cercospora blight is readily distinguished from Phomopsis and Kabatina blights of junipers. The branches of *Cercospora* infected trees usually will be devoid of foliage near their bases but will have healthy foliage on their tips (fig. 51–2); branches of trees infected with *Phomopsis* and *Kabatina* will have dead tips.

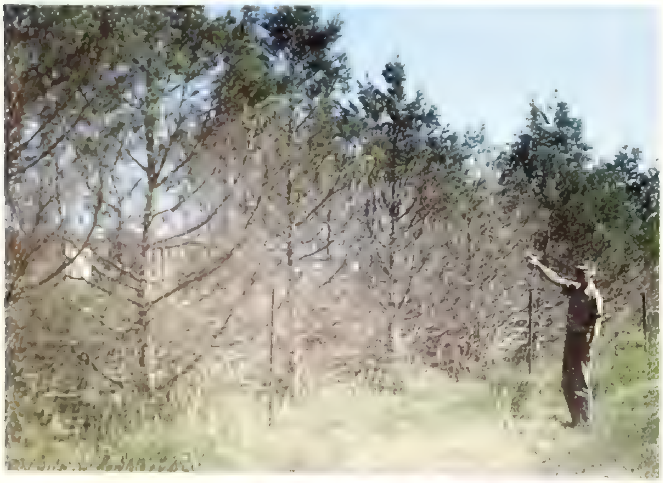


Figure 51-2. Typical appe[illegible] Mountain juniper.

Juniper foliage is of three types: (1) whip leaves characteristic of long shoot growth on the ends of secondary and tertiary branches; (2) spur leaves characteristic of short (spur) branches; and (3) juvenile leaves characteristic of seedlings.

Early symptoms are bronzed tips of leaves on spur shoots. Subsequently these leaves become entirely bronzed, then necrotic. Commonly, all leaves of a branchlet are affected. Infected foliage on branchlets usually dies in late September.

Affected branchlets drop from trees in October and November, resulting in the typical appearance of *Cercospora* infected trees—the extremities of the branches bear healthy green foliage and the inner crown is devoid of foliage. Following severe infection, juvenile foliage commonly develops on branches that previously have had only spur and whip foliage.

Disease Cycle

Spores of the fungus (fig. 51–3) are dispersed from late April through October. Dispersal may not be abundant until late May or June, and no spores are dispersed during rainless periods. There is little or no long-distance wind dispersal of spores; no spores were collected in traps located 6 feet from severely infected trees. Moisture is required for spores to germinate and for the fungus to penetrate foliage. Infection has been severe when rainfall during the growing season was at or above average. Infection was slight during the drought years of 1975 and 1976 in eastern Nebraska.

Junipers in eastern Nebraska are infected first in early to midsummer. The period between initial infection and first appearance of symptoms is between 2 and 3 weeks.

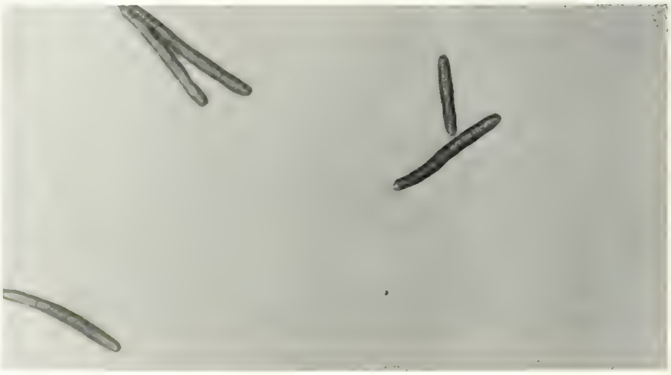


Figure 51-3. Spores of *C. sequoiae* var. *juniperi.*

The disease develops more rapidly in juvenile leaves than in spur leaves. Also, both current-year and previous-years' juvenile leaves become infected, whereas only the previous-years' spur leaves become infected.

Fruiting bodies (sporodochia) (fig. 51–4) resulting from current-season's infection were observed in both spur foliage and juvenile foliage in September. They sporulated readily when incubated at 75°F and 100 percent relative humidity for 18 hours.

Damage

The disease is found more frequently, develops more rapidly, and causes greater mortality in *J. scopulorum* than in *J. virginiana.* This fungus has not been a threat to production of juniper seedlings in the Great Plains; it is seldom found on nursery seedlings. However, *Cercospora* infection has been commonly observed in nurseries on grafted selections of junipers, particularly selections of *J. scopulorum* that have been kept in the nursery for 5 or 6 years.

Tips of secondary and tertiary branches on 10-year-old *J. virginiana* were free of infection for an average distance of 1.5 feet. The disease had extended an average distance of 11 inches along the branches the previous year. Lack of infection on tips may be a result of less moisture on the outermost foliage because of more rapid drying. Whip foliage, which develops on branch tips, also may be resistant to infection.

Trees planted in north-south rows had much more infection on the west side than on the east side. The longer persistence of moisture from dew or evening rains on the west side probably accounts for the higher levels of infection.

Control

Because whip and spur foliage are not infected before late June (and then only previous years' foliage become infected), a highly persistent fungicide applied before late June could protect trees with only spur and whip foliage for the entire season. Because of fungicide weathering, however, an additional application in late July usually is required.

Because both current-year and previous years' juvenile foliage become infected, juniper trees containing juvenile leaves would require additional fungicide applications. Bordeaux mixture (8-8-100) provided a high degree of disease supression in control tests.

Park managers following control procedures outlined above have controlled Cercospora blight on *J. scopulorum* and on *J. virginiana* since 1973. The timing of fungicide applications (figure 51–5) was developed from tests in eastern Nebraska. Timing should be modified slightly in other areas—earlier applications in southern locations.

Cercospora blight is found more frequently in new plantings of *J. scopulorum* than in new plantings of *J. virginiana.* Where *Cercospora* may be a problem, it would be better to plant *J. virginiana.*

Genetic resistance to *Cercospora* is currently being evaluated.

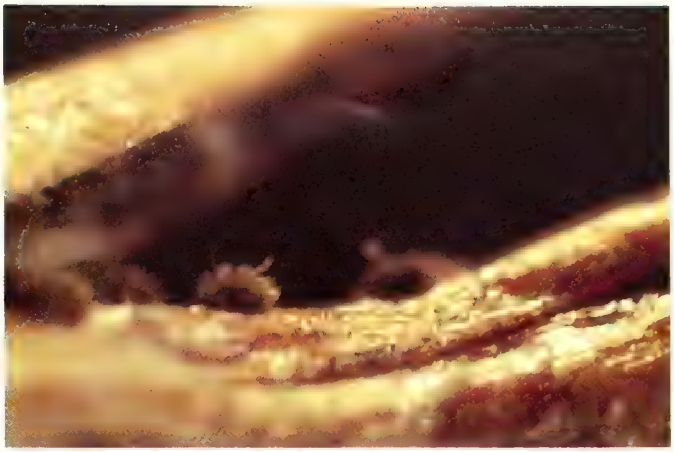


Figure 51–4. Fruiting bodies of *C. sequoiae* var. *juniperi* showing fuzzy gray appearance of conidia and conidiophores.

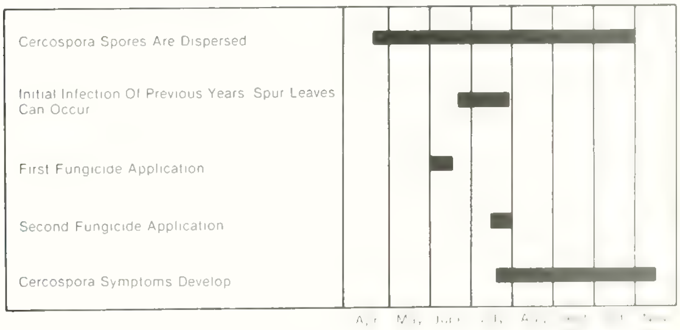


Figure 51–5. Schedule for developing programs for control of Cercospora blight.

Selected References

Hodges, Charles S. Comparison of four similar fungi from *Juniperus* and related conifers. Mycologia. 54: 62–69; 1962.

Peterson, Glenn W. Control of juniper blight caused by *Cercospora sequoiae juniperi.* American Nurseryman. 145(12): 13, 50–51; 1977.

Peterson, Glenn W. Epidemiology and control of a blight of *Juniperus virginiana* caused by *Cercospora sequoiae* var. *juniperi.* Phytopathology. 67: 234–238; 1977.

Peterson, Glenn W. Pine and juniper diseases in the Great Plains. Gen. Tech. Rep. RM–86. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1981. 47 p.

Peterson, Glenn W.; Wysong, David S. Cercospora blight of junipers: Damage and control. Plant Disease Reporter. 52: 361–362; 1968.

52. Kabatina Tip Blight of Junipers

Andrea Ostrofsky and Glenn W. Peterson

Eastern redcedar and Rocky Mountain juniper, native to the Great Plains, are important trees in windbreak, wildlife, and landscape plantings. Branch tips of both tree species have been damaged by the fungus, *Kabatina juniperi*.

Hosts and Distribution

Inoculation studies and observations by European workers indicate that, in addition to infecting *Juniperus virginiana* and *J. scopulorum*, the fungus may infect many other junipers including *J. deppeana*, *J. squamata*, *J. chinensis*, *J. communis*, *J. sabina*, and *J. horizontalis*. *Kabatina juniperi* was found recently on ornamental junipers in Ontario. In the United States, the fungus has been found in Nebraska, Indiana, Wisconsin, New Jersey, New Hampshire, and Maine, and is probably more widespread.

The closely related *Kabatina thujae* is a pathogen of *Thuja*, *Chamaecyparis*, and *Cupressus*. Some consider the two fungi similar enough to be the same species, referring to the juniper pathogen as *K. thujae* var. *juniperi*. Further studies of isolates from both Europe and North America are needed to clarify the taxonomy of the genus.

Symptoms and Signs

Symptoms of infection become apparent in early spring, before shoot growth begins. When healthy juniper foliage loses its winter coloration and turns green, diseased foliage turns yellow-brown (fig. 52–1). The discolored portion of infected branch tips averages about 5 inches long in eastern Nebraska. Small, black fruiting bodies called acervuli are usually present in a sunken grayish area at the base of the discoloration (figs. 52–2, 52–3).

The rounded to ellipsoidal fruiting bodies may be found beneath the host epidermis as early as February. They break through the host epidermis beginning in March, and are numerous in April and May; numbers decrease throughout the summer. Occasionally acervuli can be found in September and October.

Conidia are produced successively at the tips of tapered spore-bearing cells that cover the surface of the acervulus (fig. 52–4). The conidia (4.5–8 μm by 2.3–3 μm) are hyaline, ellipsoid, and unicellular. The presence of conidia and spore-bearing cells results in a granular appearance of the surface of the acervulus (fig. 52–3).

Disease Cycle

K. juniperi enters plants through wounds. Many insects are known to feed on the foliage and branches of junipers, including larvae of species of *Dichomerus* and *Contarinia*. These insects make wounds through which the fungus could infect the trees.

In Nebraska, symptoms on naturally infected junipers

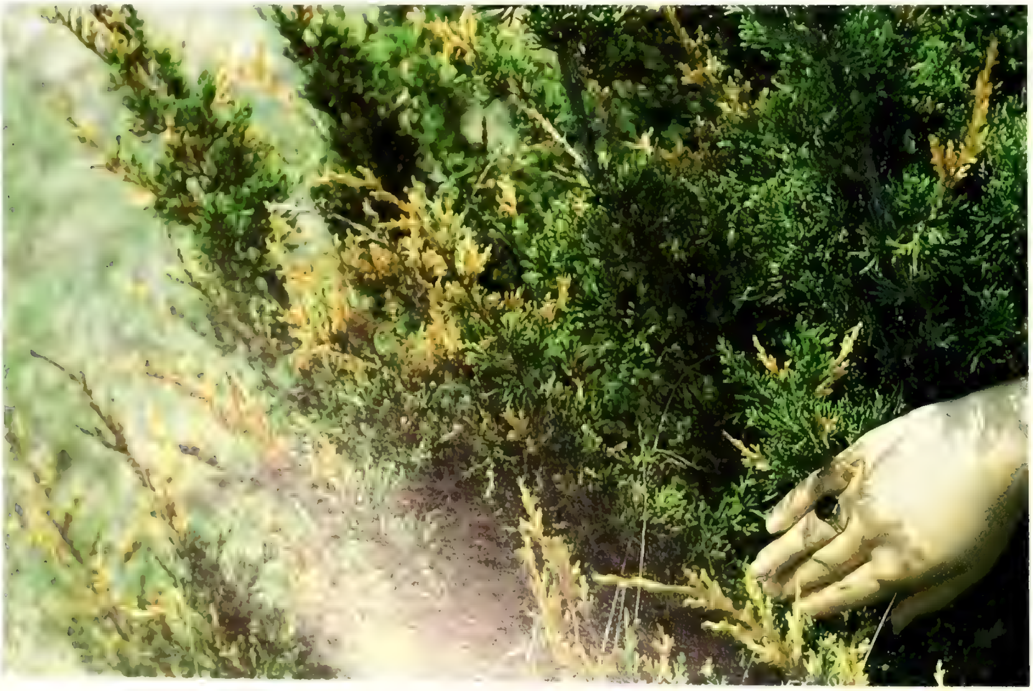


Figure 52-1. Branches of eastern redcedar infected with *Kabatina juniperi*. Note the discoloration and dieback of the branch tips.

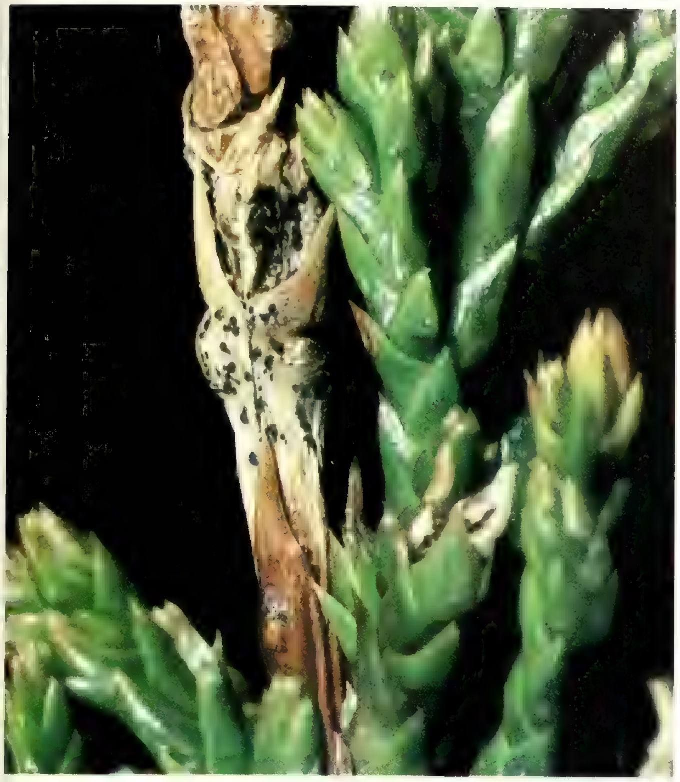


Figure 52-2. Base of discolored zone of infected eastern redcedar branch. Note the numerous small, dark acervuli.

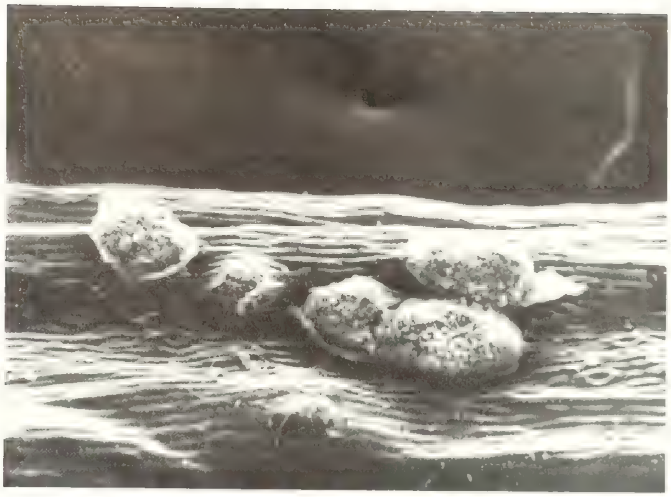
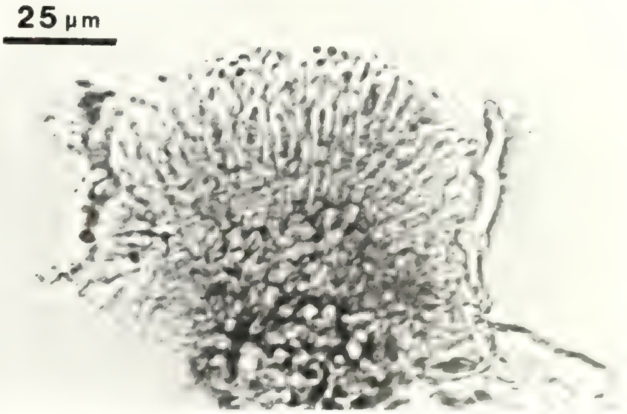


Figure 52-3. Acervuli of *K. juniperi* that have broken through the host epidermis. Note the granular appearance of the surface. [Approximately X100].

Figure 52-4. Cross section through an acervulus of *K. juniperi*. One-celled spores are formed on the surface of the acervulus. [Approximately X500].



appear in the spring on tissues produced the previous year. This occurrence, plus the absence of acervuli during the winter, suggests that infection occurs during the previous growing season. The fungus, which can survive cold temperatures, probably overwinters within the branchlets.

The fungus can be grown in culture. Colony characteristics vary with isolate and medium, but colonies are usually flat, dark, and sometimes have sparse aerial mycelium. Spores are produced on denticles (tooth-like projections) on the sides of vegetative hyphae. Large numbers of spores form mucoid masses on the colony surface.

The optimum temperature for both germination and growth of Nebraska isolates of *K. juniperi* is 75°F, although germination, growth, and infection can take place at cooler temperatures. High relative humidity (95 percent or greater) also favors infection.

Damage and Control

Any disease that reduces the growth or esthetic value of junipers in the Great Plains warrants attention. *Kabatina thujae*, closely related to *K. juniperi*, has caused serious shoot mortality in members of the Cupressaceae. Current levels of infection of junipers by *K. juniperi* in the Great Plains, however, are not serious enough to warrant control in windbreak or farmstead plantings. Control in landscape plantings may be desirable for esthetic reasons, but no specific techniques have yet been developed. Control of wounding agents such as insects may reduce infection levels. Pruning and destruction of infected branchlets may reduce levels of inoculum, but would result in more wounded tissue. European studies indicate that *K. thujae* is sensitive to the fungicide mancozeb. The unsightly appearance of infected trees is often improved when lower branches elongate and the dead branch tips fall from the tree.

Selected References

Funk, A.; Molnar, A. C. *Kabatina thujae* on yellow cedar in British Columbia nurseries. Canadian Forestry Service Bimonthly Research Notes. 28: 16–17; 1972.

Ostrofsky, Andrea; Peterson, Glenn W. Occurrence of *Kabatina juniperi* on *Juniperus virginiana* in eastern Nebraska. Plant Disease Reporter. 61: 512–513; 1977.

Ostrofsky, Andrea; Peterson, Glenn W. Etiologic and cultural studies of *Kabatina juniperi*. Plant Disease. 65: 908–910; 1981.

Perry, R. G.; Peterson, J. L. Susceptibility and response of juniper species to *Kabatina juniperi* infection in New Jersey. Plant Disease. 66: 1189–1191; 1982.

53 Brown Spot Needle Blight of Pines

Albert G. Kais and Glenn W. Peterson

Brown spot needle blight has long been a problem in the South. Within the last 20 years it has become a problem in the North, particularly in Christmas tree plantings.

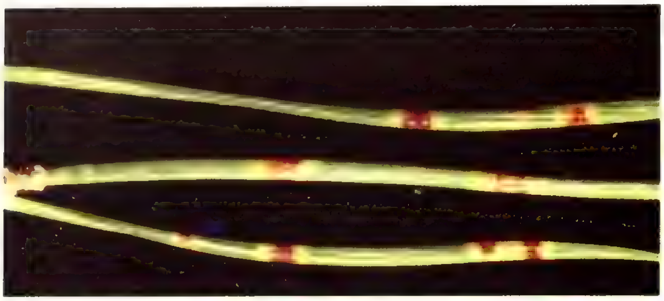


Figure 53-1. Symptoms on Scots pine needles.

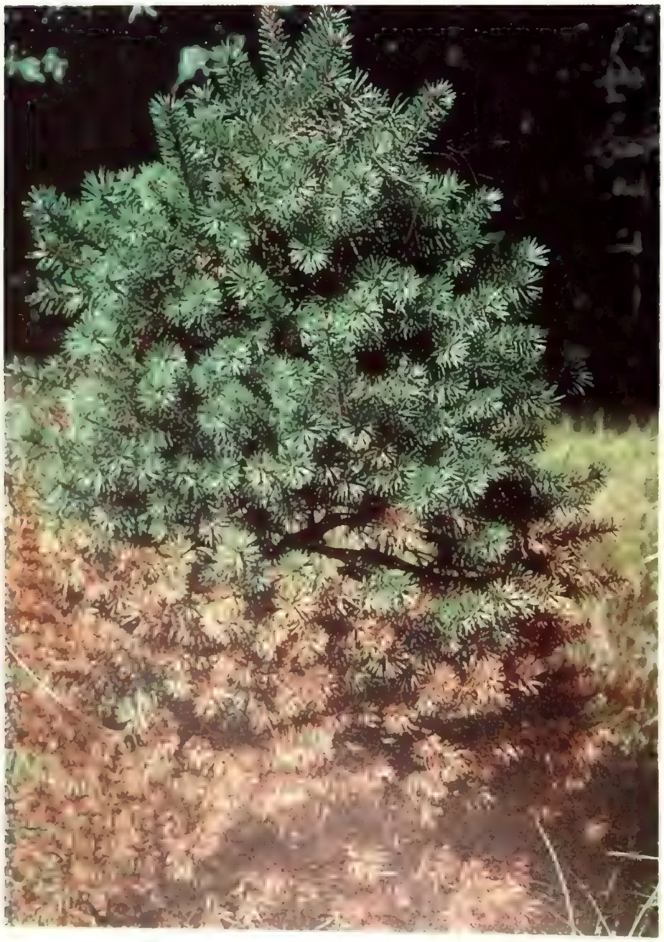


Figure 53-2. Brown spot on Scots pine tree.

Hosts and Distribution

The brown spot fungus, *Scirrhia acicola*, attacks 32 species of pine in 25 States from coast-to-coast. It is most common in the South, where it primarily attacks longleaf pine and, secondarily, other southern pine species. In the North it attacks most pines, particularly Scots pine in the mid- and north central States. Short-needled Scots pine varieties (Spanish and French green) are more susceptible than long-needled varieties (Austrian hills and German).

Symptoms and Signs

Initial symptoms appear on pine in eastern Nebraska during July. Yellow spots develop on needles and often become resin-soaked. These develop into brownish spots and conspicuous bands on Scots and ponderosa pine needles (fig. 53–1). Infected needles of all ages then start dying from the tips backward until the entire needle turns brown, and drops during the fall. The majority of infected Scots pine needles are found on lower branches on the north side of the tree (fig. 53–2). Although this pattern can result in bare branches, buds can usually produce new foliage the following spring. In severe cases, however, branches are killed.

Although the fungus has two types of spores in the South (conidia and ascospores), only the conidial spore stage (asexual) occurs in the Great Plains. Positive identification requires laboratory examination of conidia found in the fruiting bodies (acervuli). These are cylindrical, curved, 1–4 septate, 19–35 by 3.5–4.0 μm, and olive-green to brown (fig. 53–3). The fungus grows slowly on malt agar, forming conidia in an olive-green to black gelatinous matrix (fig. 53–4).

Disease Cycle

Sticky conidia oozing from fruiting bodies are responsible for disease build-up on trees and for tree-to-tree spread (fig. 53–5). These conidia are spread by rain splash, animals, and man, particularly when shearing wet foliage in Christmas tree plantations.

Conidia germinate and enter needles via stomata. The major infection period for pines in the Great Plains is June-July, although some infection can occur through September. New fruiting bodies with mature conidia are found on needles in late August, where they overwinter. With moisture present, the conidia germinate to infect developing, susceptible needles as they emerge in early summer (fig. 53–6). Mature needles are less susceptible to infection.

Damage

Brown spot has been reported to reduce total annual growth of southern pines by more than 16 million cubic feet. It is most severe on longleaf pine, inhibiting growth and causing mortality. Stem growth of heavily infected seedlings may be delayed 10 or more years.

In the North, the disease is a severe problem on certain varieties of Scots pine and other pine species used in Christmas tree plantations. Thousands of dollars have been lost annually in Christmas tree sales because excessive needle drop made trees unmerchantable. In the Great Plains, brown spot is a problem on ponderosa pine and on some varieties of Scots pine in landscape, windbreak, and Christmas tree plantings.

Control

Cultural practices, fungicidal sprays, and use of less-susceptible varieties are means for effective control of brown spot in the Great Plains. Cultural practices are: (1) use healthy nursery stock, (2) eliminate small pockets of infected trees, (3) do not plant seedlings next to older pine windbreaks, and (4) do not shear infected trees or plantations during wet weather. Fungicidal sprays of chlorothalonil (Bravo) or Bordeaux mixture, both registered by the EPA, provide excellent disease control. A first spray should be applied when new needles are nearly half grown. During wet years, or in severely infected plantations, a second spray should be applied 3–4 weeks later. Growers should use the long-needled varieties of Scots pine (Austrian hills and German) in Christmas tree plantations. Finally, to prevent catastrophic losses, tree growers should not plant all of their land to one species or variety of pine.

Selected References

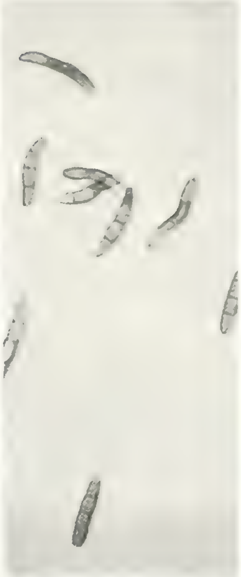
Nicholls, Thomas H.; Brown, H. Daniel. How to identify Lophodermium and brown spot diseases on pine. St. Paul, MN: U. S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1972. 5 p.

Peterson, Glenn W. Pine and juniper diseases in the Great Plains. Gen. Tech. Rep. RM–86. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1981. 47 p.

Phelps, W. R.; Kais; A. G.; Nicholls, T. H. Brown-spot needle blight of pines. Forest Insect and Disease Leaflet 44. Washington, DC: U.S. Department of Agriculture, Forest Service; 1978. 8 p.

Skilling, D. D.; Nicholls, T. H. Brown spot needle disease—biology and control in Scotch pine plantations. Forest Service Res. Pap. NC–109. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1974. 19 p.

Siggers, Paul V. The brown spot needle blight of pine seedlings. Tech. Bull. 870. Washington, DC: U.S. Department of Agriculture; 1944. 36 p.



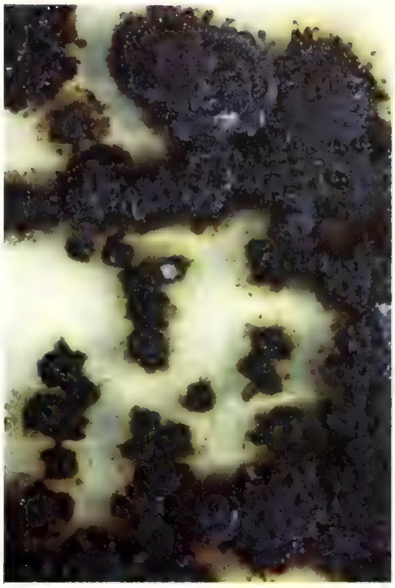
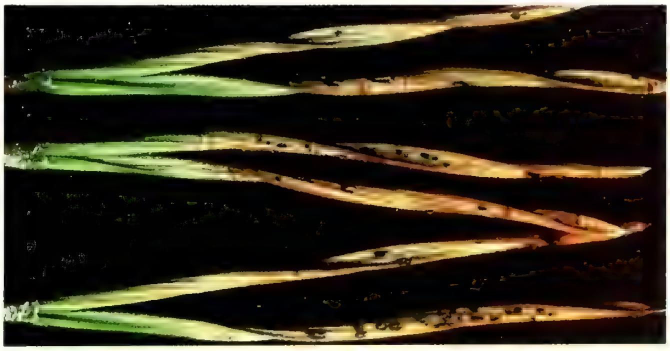


Figure 53-3. Conidia of *Scirrhia acicola* (left).

Figure 53-4. *S. acicola* growing on malt agar (right).

Figure 53-5. Fruiting bodies on needles (below).



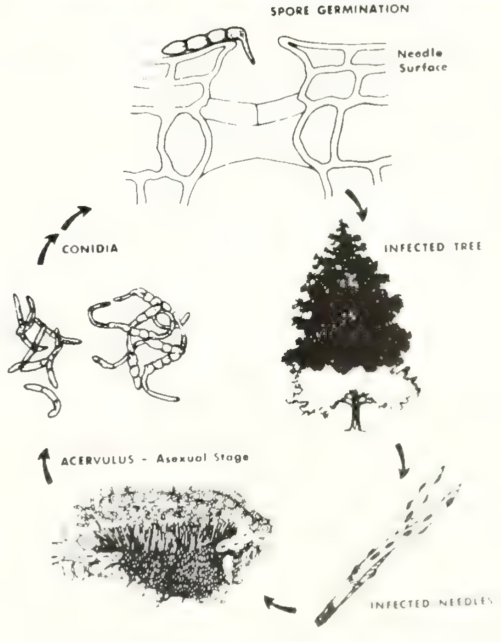


Figure 53-6. Disease cycle on Scots pine.

54. Dothistroma Blight of Pines

Glenn W. Peterson and David S. Wysong

Dothistroma blight is a devastating foliar disease of a wide range of pine species. The causal fungus, *Dothistroma pini*, infects and kills needles.

Hosts and Distribution

D. pini occurs in several plains States (fig. 54–1). Twenty pine species and hybrids are known hosts in the United States. In the central and eastern United States, the fungus is found most often in plantings of Austrian and ponderosa pines, which are highly susceptible. The fungus has not been reported in natural pine stands in the Eastern and Central States.

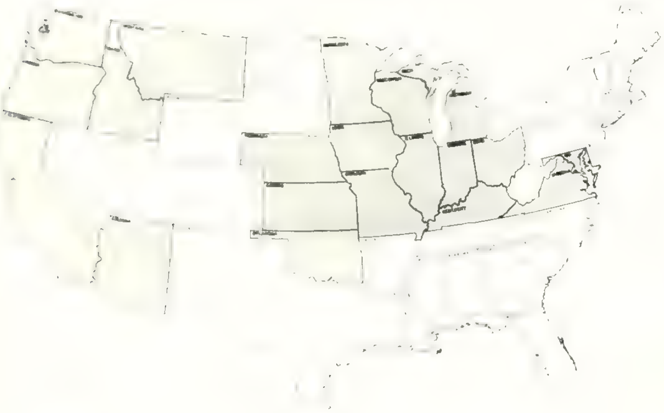


Figure 54-1. States in which *D. pini* is present (gray).

Symptoms and Signs

Early symptoms consist of deep-green bands and yellow and tan spots on needles. The deep green color of bands does not last, and can be detected only at the onset of symptom development. Later, the spots and bands turn brown to reddish brown (fig. 54–2). The bands are brighter red and more numerous on pines in California, Oregon, Washington, and Idaho, where this disease is often referred to as the "red band" disease.

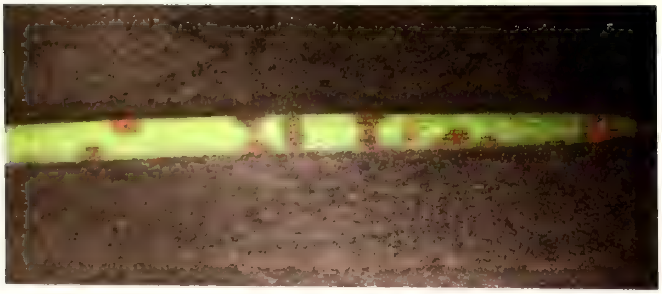


Figure 54-2. Spots and bands on infected pine needles.

The ends of infected needles progressively turn light green, tan, and brown, with the base of the needles remaining green (fig. 54–3). Needles may develop extensive necrosis (browning) 2 to 3 weeks after the first appearance of symptoms. Spores of the fungus are borne in fruiting bodies (acervuli) which develop below the epidermis of needles. As the acervuli enlarge, they split the epidermis longitudinally along two sides of the acervulus (fig. 54–4). Infection is typically most severe in the lower crown. Infected needles drop prematurely. Infected second-year needles are cast before infected current-year (first-year) needles. In some seasons, second-year needles are cast in the late fall of the year they became infected. In other seasons, loss of second-year needles is not extensive until late the following spring or early summer. Needles that become infected the year they emerge often are not shed until late summer the following year.

Disease Cycle

The fungus has both a sexual stage (*Scirrhia pini*) and

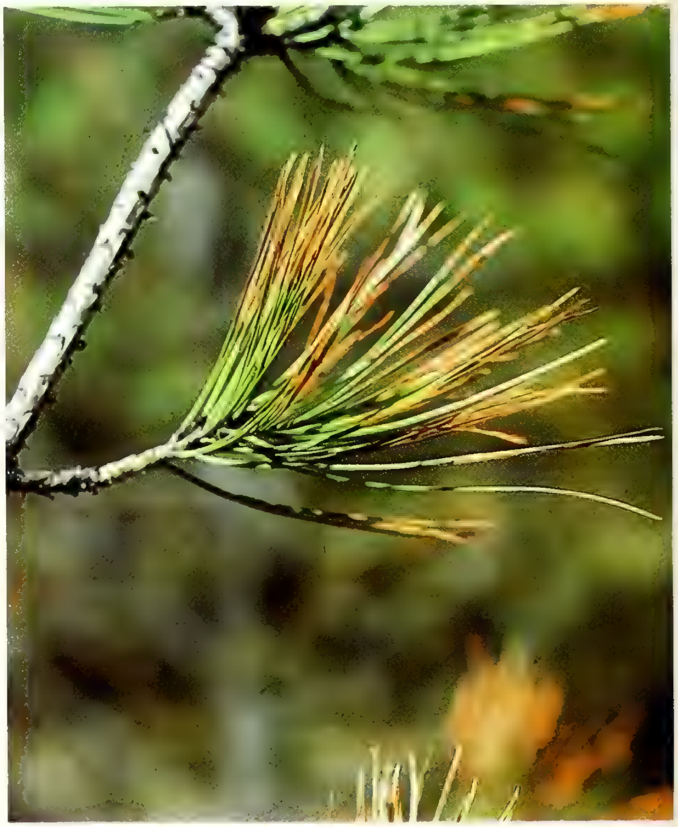


Figure 54-3. Typical appearance of infected needles: needle tips brown, needle bases green.

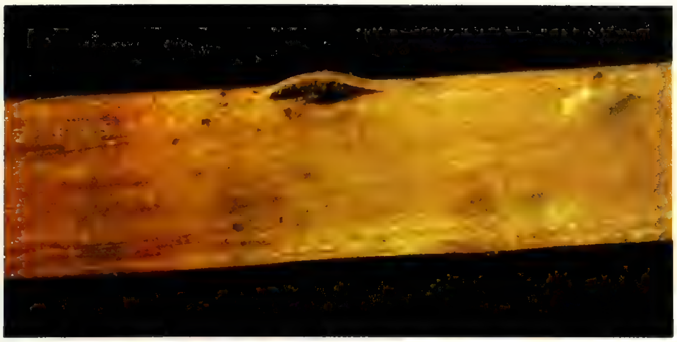


Figure 54-4. Fruiting bodies of *D. pini* raising the epidermis on a needle.

an asexual stage (*Dothistroma pini*). In the United States, the sexual stage has been found only in Alaska, California, and Oregon. The stromata of the sexual stage produce ascospores, whose role in the development of epidemics is not known, whereas much is known about the role of conidia (spores produced by the asexual stage) in disease development (fig. 54–5).

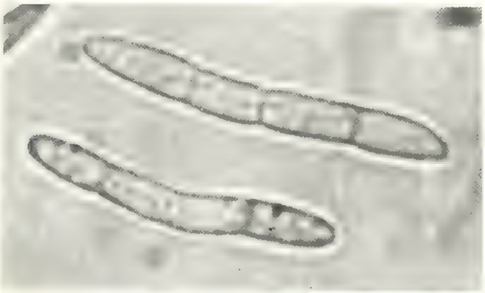


Figure 54-5. Conidia of *D. pini.*

The stromatic acervuli in which conidia are formed may develop sufficiently in the fall to raise and split the needle epidermis. They generally do not mature and produce conidia until the following spring. The conidia, which are exposed as the epidermis is raised, are released during wet weather and dispersed by rainsplash any time during the growing season. Thus, new infections can occur any time it rains from May to October. However, symptoms do not appear on newly infected needles until early fall in the Central United States.

Two growing seasons are required for completion of the life cycle in most areas of the United States (in California and Oregon, the cycle may be completed in 1 year).

Although the fungus has seldom been detected in young seedlings in nurseries, epidemics in isolated new plantings in the central Great Plains indicate that trees infected in the nursery must have been responsible. The fungus is common on older transplants in nurseries that produce pines for landscape plantings.

Damage

Successive years of severe infection result in decreased growth and, ultimately, death. The disease makes pines in landscapes unsightly and in Christmas tree plantings unmarketable. Premature defoliation caused by this fungus has resulted in complete failure of most ponderosa pine plantings in States east of the Great Plains. In the central and southern Great Plains, *D. pini* damages Austrian and ponderosa pines in Christmas tree, windbreak, and landscape plantings. In California, Oregon, and Washington, the fungus damages plantings of lodgepole and Monterey pines. Infection by *D. pini* occurs sporadically in natural stands of lodgepole and ponderosa pines in Idaho, Montana, and Washington.

Control

Copper fungicides effectively prevent infection by *D. pini.* Bordeaux mixture applied twice in the growing season has provided good protection of pines in the Central United States. Chlorothalonil also is registered for control of Dothistroma blight only in the North Central States.

The first application (mid-May) protects needles from previous seasons; the second application protects current-year needles. When control is intended for plantings of Austrian or ponderosa pines, the second application can be made after considerable new growth has occurred because current-year needles of these species initially resist infection and do not become susceptible until midsummer (July).

Effective control also has been obtained in plantings in the Central United States with a single application made after considerable growth has occurred (early June). There is some risk in this procedure, since infection could occur in previous years' needles before the early June application. A single application will control this disease on trees that do not have susceptible current-year needles. Many Christmas tree growers in the Central United States are effectively controlling Dothistroma with a single fungicide application.

Annual spraying may not be necessary in park, residential, and similar types of plantings. If infection occurs during a year in which fungicide has not been applied, fungicide can be applied the next year with confidence that good control will be obtained. If little or no infection occurs the year fungicide was not applied, spraying can be skipped for another year. Christmas tree growers should probably spray annually, however,.

The use of genetic resistance looks promising for preventing or reducing damage by this fungus. Seed from a Yugoslavian source, which has shown high resistance, is currently used to produce Austrian pines for Great Plains plantings. Recently, several geographic sources of ponderosa pine have been identified as having high resistance. Needles of all ages are highly resistant on some trees. On other trees, current-year needles are resistant, but older needles are susceptible.

Selected References

Peterson, Glenn W. Dothistroma needle blight of Austrian and ponderosa pines: epidemiology and control. Phytopathology. 57: 437–441; 1967.

Peterson, Glenn W. Resistance to *Dothistroma pini* within geographic seed sources of *Pinus ponderosa*. Phytopathology. 74: 956–960; 1984.

55. Naemacyclus (Cyclaneusma) Needle Cast of Pines

Glenn W. Peterson and James A. Walla

Needle cast caused by *Naemacyclus minor* (*Cyclaneusma minus*) occasionally causes damage to Scots pines in young plantings in the Great Plains.

Hosts and Distribution

N. minor infects several pines including Scots, Austrian, and ponderosa pines. Distribution in the Great Plains is seemingly sporadic. Young plantations of Scots pines have been infected in North Dakota, South Dakota, Nebraska, and Kansas. The fungus has also been found on ponderosa pine in Nebraska and North Dakota.

Symptoms and Signs

The largest number of needles develop symptoms during September-November of their second growing season; however, some infected needles may not develop symptoms until spring, summer, or fall of the third growing season. The first symptoms appear as small, light green spots which gradually lighten and coalesce, turning the entire needle a dusty yellow (figs. 55–1, 55–2) with distinct transverse brown bars. Needles becoming symptomatic during the summer usually are cast during the summer or fall. Needles becoming symptomatic during the summer or fall may be cast during the fall or winter, or may remain attached to the tree through the following spring. Off-white, waxy fruiting bodies develop on the symptomatic needles, usually within 1 month after symptoms appear (fig. 55–3). Fruiting bodies are particularly distinctive when they swell during wet weather; they are often conspicuous on recently cast needles.

Symptoms of this disease may be confused with natural needle senescence or damage caused by aphids. The presence of apothecia are diagnostic of *Naemacyclus*.

Disease Cycle

According to research in Pennsylvania, Scots pine needles become susceptible in July of the first growing season, and remain susceptible until they are naturally cast. Four distinct infection periods have been defined in Pennsylvania. The first infection period is from mid-July to August, and usually accounts for 5 percent of total infection; the second is from September through November, and may account for 0–60 percent (usually

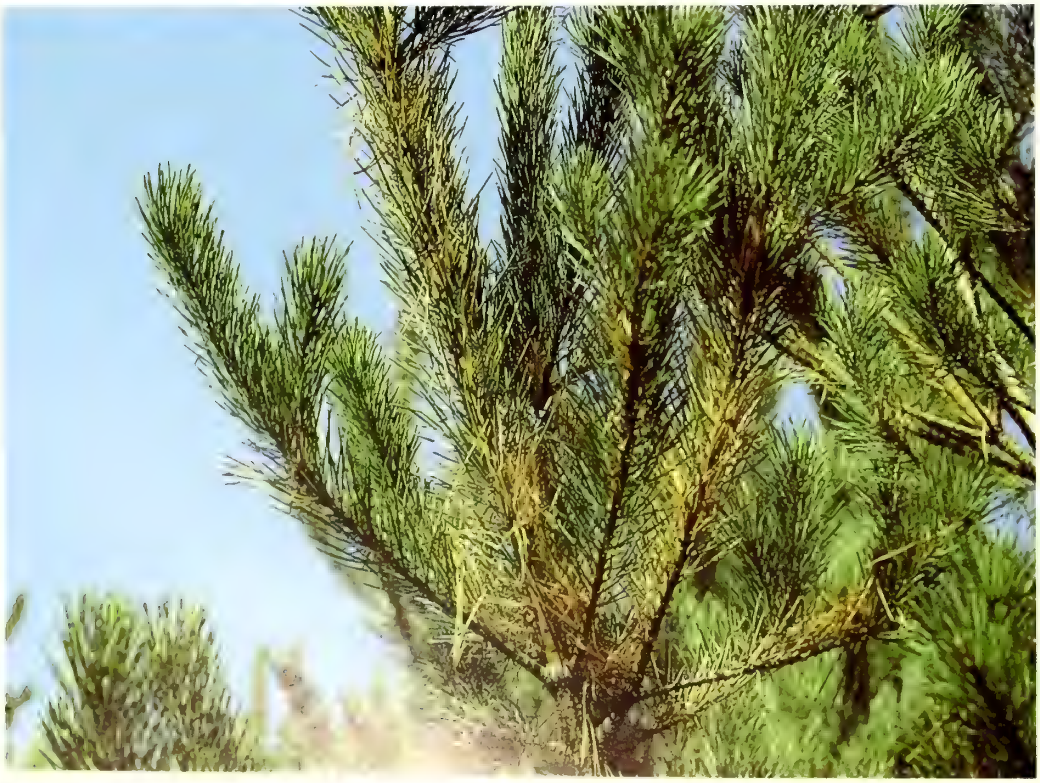


Figure 55-1. Scots pine infected with Naemacyclus needle cast fungus.

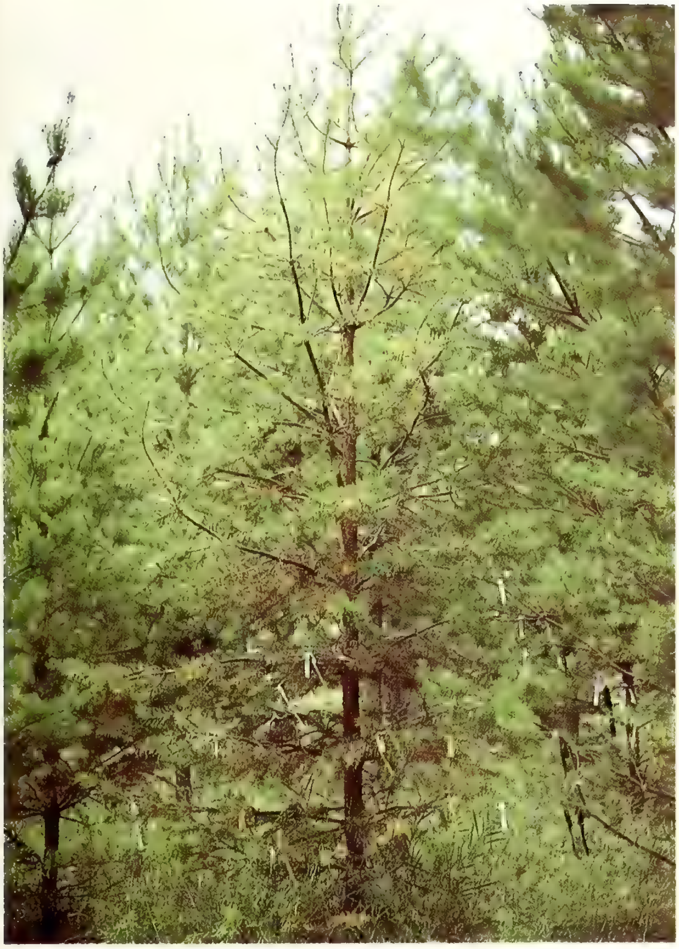


Figure 55-2. Scots pine infected with Naemacyclus needle cast fungus.

about 5 percent) of total infection; the third may occur in late November-early December, and usually is insignificant. These three infection periods during the first growing season usually account for 10–35 percent of the total infection, but some years account for 60 percent of the total infection. The fourth infection period usually begins in early April and extends through June of the second growing season; this period normally accounts for 50 percent of total infection.

Apothecia develop within 15 months of infection. The spores produced in apothecia are dispersed by wind after rainfall.

Damage

This fungus has caused extensive damage to Scots pines in Christmas tree plantings in some eastern and central States, but damage has been slight in the Great Plains. Severe infection results in yellow needles and reduced foliage, thereby reducing windbreaking ability, growth, and aesthetic value. The most extensive damage observed in the Great Plains was on Scots pine in neglected Christmas tree plantings in South Dakota, and in a crowded 11-year-old planting in North Dakota. The fungus has been found on cast needles in a 10-year-old planting of ponderosa pine in Nebraska; no damage was apparent.

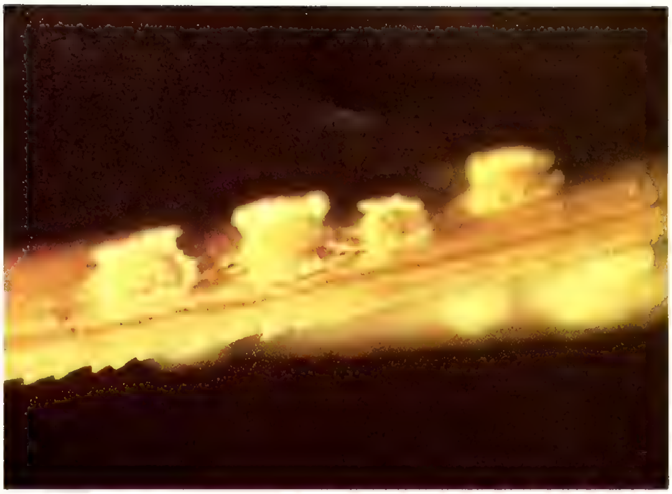


Figure 55-3. Fruiting bodies of *Naemacyclus minor*

Control

Control by fungicides is possible but several applications are needed. In Pennsylvania chlorothalonil (Bravo 500) applied four times between late March and early October has given good control.

Silvicultural practices that increase air movement through plantings, or increase distances between susceptible trees should reduce amount of infection.

There is considerable variation in susceptibility to this fungus among Scots pine provenances; scientists in Pennsylvania are seeking to identify resistant individuals for use in seed orchards.

Selected References

DiCosmo, F.; Peredo, H.; Minter, D. W. *Cyclaneusma* gen. nov., *Naemacyclus* and *Lasiostictis*, a nomenclatural problem resolved. European Journal of Forest Pathology. 13: 206–212; 1983.

Kistler, B. R.; Merrill, W. Etiology, symptomology, epidemiology and control of Naemacyclus needlecast of Scotch pine. Phytopathology. 68: 267–271; 1978.

Merrill, W.; Kistler, B. R.; Zang, L.; Bowen, K. Infection periods in Naemacyclus needlecast of Scots pine. Plant Disease. 64: 759–761; 1980.

Wenner, N. G.; Merrill, W. Cyclaneusma needlecast in Pennsylvania: a review. In: Peterson, G. W., tech. coord. Recent research on conifer needle diseases. Proceedings of the International Union of Forestry Research Organizations Working Party on Needle Diseases Conference; 1984 October 14–18; Gulfport, MS. Gen. Tech. Rep. W0-50. Washington, DC: U.S. Department of Agriculture, Forest Service; 1985: 35–40.

56. Rhizosphaera Needle Cast of Spruce

Darroll D. Skilling and James A. Walla

Rhizosphaera needle cast is caused by the fungus *Rhizosphaera kalkhoffii*. The disease was first observed on ornamental blue spruce in Connecticut in 1938.

Hosts and Distribution

The primary host for *Rhizosphaera* is blue spruce. Although it also infects white spruce, its variety Black Hills spruce, and Engelmann spruce, it is not considered a serious problem on these species. Douglas-fir has also been reported as a host. The disease is primarily a problem in nurseries, ornamental plantings, and Christmas tree plantations. It has been found in natural stands, but apparently the fungus causes little damage under these conditions.

The disease is currently causing serious damage in blue spruce Christmas tree plantations in Wisconsin, Michigan, Minnesota, Indiana, and Pennsylvania. A 1972 survey of 98 ornamental nurseries in Wisconsin showed the disease present on 12 percent of the blue spruce stock in 18 nurseries. The disease has also been found on ornamental blue spruce in Connecticut, New York, Massachusetts, Virginia, North Carolina, North Dakota, South Dakota, Quebec, and New Brunswick, and on natural blue spruce stands in Arizona. It has been found in natural Engelmann spruce stands in Colorado.

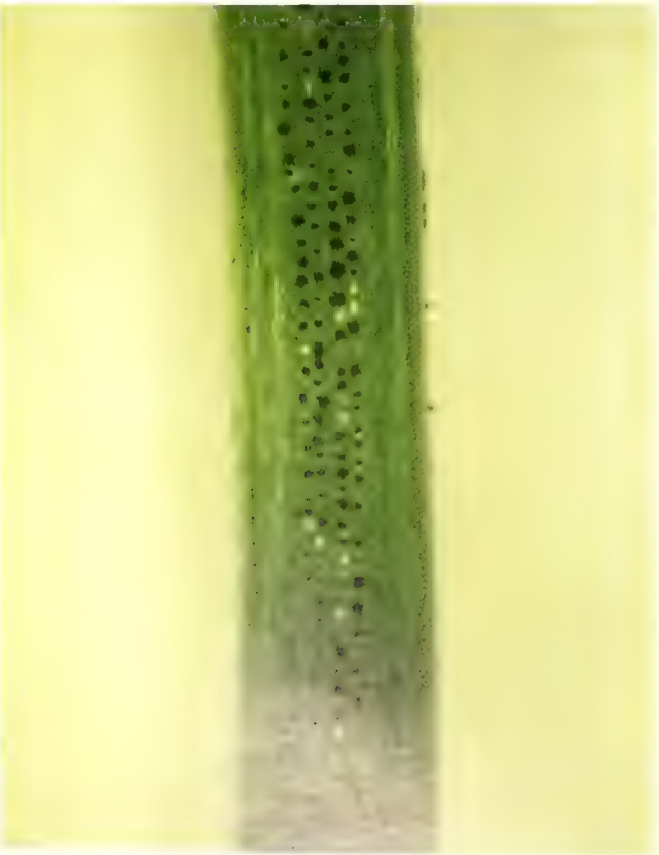


Figure 56-1. Fruiting bodies of Rhizosphaera kalkhoffii protruding from stoma [illegible]

Symptoms and Signs

R. kalkhoffii infects blue spruce of all ages. Although infection takes place in the spring, the first symptoms are not visible until the following spring. Small dark brown or black spherical fruiting bodies (pycnidia) emerge through the stomata of infected needles (fig. 56–1). They can easily be seen with a hand lens throughout the year. Infected needles turn yellow in July and purplish brown by late August of the year following infection (fig. 56–2). The infected needles usually fall off in late summer of their second growing season, although some adhere over winter and produce spores the following spring. Needles on the lowest branches are usually infected first and the disease gradually progresses up the tree (fig. 56–3). On severely infected branches only current-year needles will be present as the second-year needles drop off in early summer.

Disease Cycle

The pycnidia on infected needles release conidia in late spring during periods of wet weather. Hyaline conidia (4 by 8 μm) are dispersed primarily by rainsplash to infect the newly emerging needles. Pycnidia will emerge from the stomata of these newly infected needles the following spring to start a new life cycle.

Damage

Although some tree mortality has been observed under epidemic conditions, the primary damage involves premature needle cast. Branches defoliated each year for 3 to 4 years will die. The trees become unsightly for ornamental purposes and are unmerchantable for quality Christmas trees. In the Great Plains, heavy infection occurs primarily in years with greater-than-normal spring rainfall.

Control

Cultural–The most important control procedure for this disease is to plant only healthy stock. Blue spruce

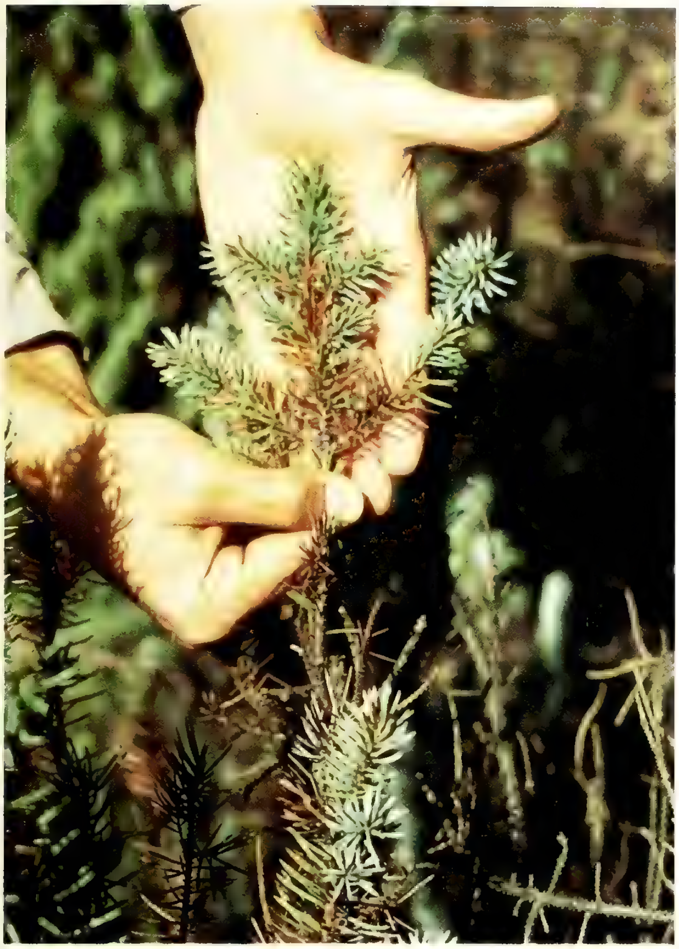


Figure 56-2. Infected needles eventually turn purplish-brown.

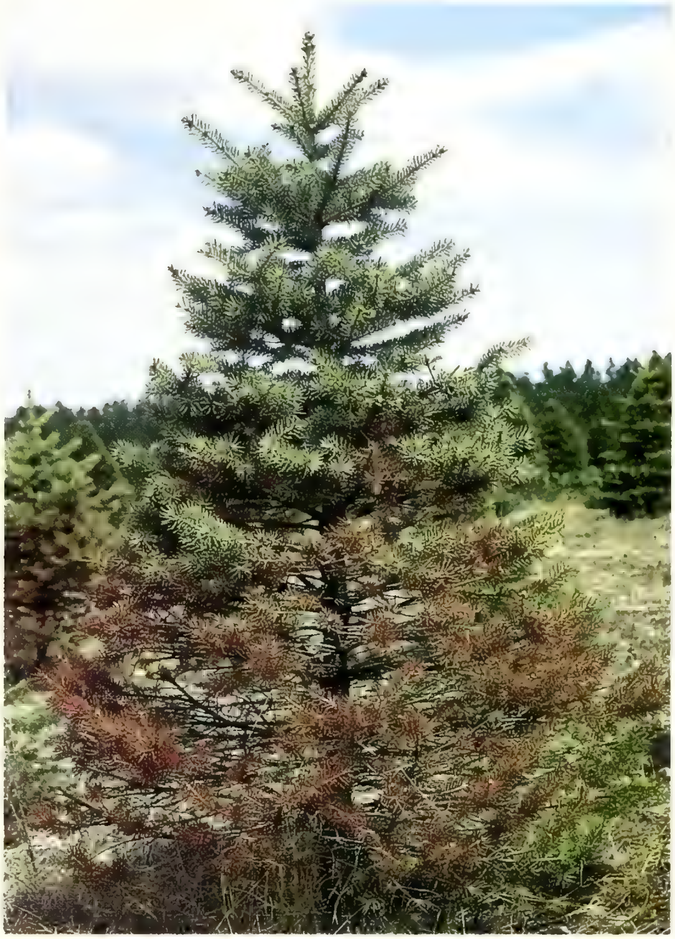


Figure 56-3. Rhizosphaera needle cast damage is most severe on lower portion of tree.

seedlings from nurseries should be inspected carefully for fruiting bodies of *Rhizosphaera* within the stomata. Infected seedlings should be returned to the nursery. Blue spruce plantations should be examined frequently for signs of Rhizosphaera needle cast. If the trees seem to be dropping their needles prematurely, a careful inspection should be made for the fruiting bodies of *Rhizosphaera* in the stomata of the needles. These can be observed throughout the year. Early identification of this problem will result in easier control as light infections can be controlled with only one or two fungicide sprays.

During shearing operations, healthy Christmas tree plantations should be sheared first to avoid the possibility of spreading fungus spores on the workers' clothes or shearing tools. Shearing tools can be sterilized by dipping in denatured alcohol for 3 minutes. Infected trees should not be sheared when the foliage is wet because the conidia are more easily spread to healthy trees at this time.

If possible, do not place new plantings adjacent to established trees. Do not bring infected needles into the area (such as spruce Christmas trees or branches). Promote good air circulation by maintaining open spacing and by mowing grass and brush.

Chemical–Infected trees can be sprayed with Bordeaux mixture 8-8-100 or chlorothalonil (Bravo). Both are effective and are registered for use. Fungicides applied in early June and again in early July give the most economical control in Minnesota and Wisconsin. In areas with a different growing season the spray schedule should be adjusted so that a protective spray is applied when the new needles are half elongated and again when needles are fully elongated. Two years of fungicide spraying will usually restore moderately infected trees to full foliage quality. Heavily infected stands will require more spraying. Early treatment will usually control Rhizosphaera needle cast after only one year's spraying. This may be the only treatment necessary until final harvest.

Selected References

Anonymous. Plant Industry Report, Wisconsin Department of Agriculture 10(1): 3–4; 1974.

Hawksworth, Frank G.; Staley, John M. *Rhizosphaera kalkhoffii* on spruce in Arizona. Plant Disease Reporter. 52: 804–805; 1968.

Waterman, Alma M. *Rhizosphaera kalkhoffi* associated with a needle cast of *Picea pungens*. Phytopathology. 37: 507–511; 1947.

57. Western Gall Rust of Pines

Glenn W. Peterson and James A. Walla

Western gall rust is a disease that affects pines in nurseries and in plantings in the Great Plains.

Hosts and Distribution

The western gall rust fungus, *Endocronartium (Peridermium) harknessii,* infects many native hard pines, including ponderosa, lodgepole, and jack pines, as well as the exotic Scots and mugo pines. Western gall rust generally is found throughout the pine forests of western and northern North America, the northern Great Lakes region, and in scattered locations in eastern North America. The fungus occurs in natural stands and stringers of ponderosa pine in and adjacent to the western Great Plains.

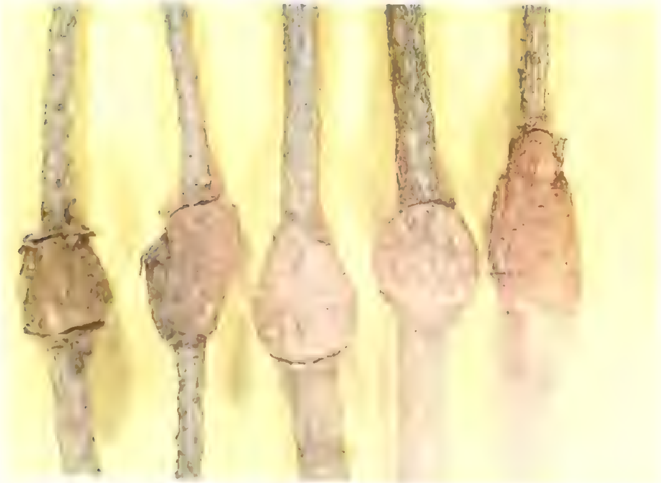
Symptoms and Signs

The disease is characterized by globose to pear-shaped galls (fig. 57–1) on branches and stems of pines of all ages (fig. 57–2). These galls are most conspicuous in the spring, when the gall surface ruptures, exposing bright orange spores (fig. 57–3). Cankers sometimes form on main stems; such cankers are usually associated with branch galls adjacent to main stems. Witches'-brooms sometimes develop following infection.

Disease Cycle

Spores form in the spring in galls on pine branches and stems. They are dispersed in May and June, and infect current-year shoots. Galls form mostly in the summer following the year of infection. Galls formed in the summer produce spores the following spring. Thus the time from infection to first sporulation is usually 2 years. Spores can directly infect other pines rather than go through an alternate host. Spores continue to be formed in galls year-after-year.

Figure 57-1. Galls of various shape on ponderosa pine branches infected by *Endocronartium harknessii.*



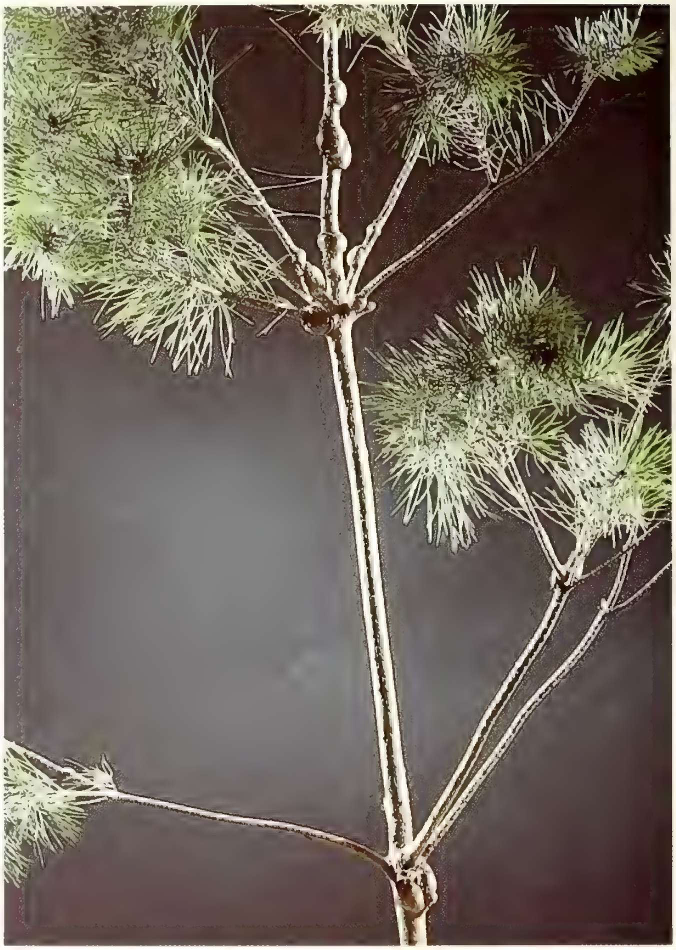


Figure 57-2. Galls on Scots pine infected by *E. harknessii.*

Damage

Because the fungus spreads from pine to pine, even a single infected seedling can ultimately result in an epidemic of western gall rust in plantings. Stem galls (fig. 57–4) may make up to 10 percent of nursery seedlings unsalable. Galls may weaken the stems, resulting in wind breakage. Abundant galls on branches may cause [illegible] stunting or mortality. Pines in landscape and

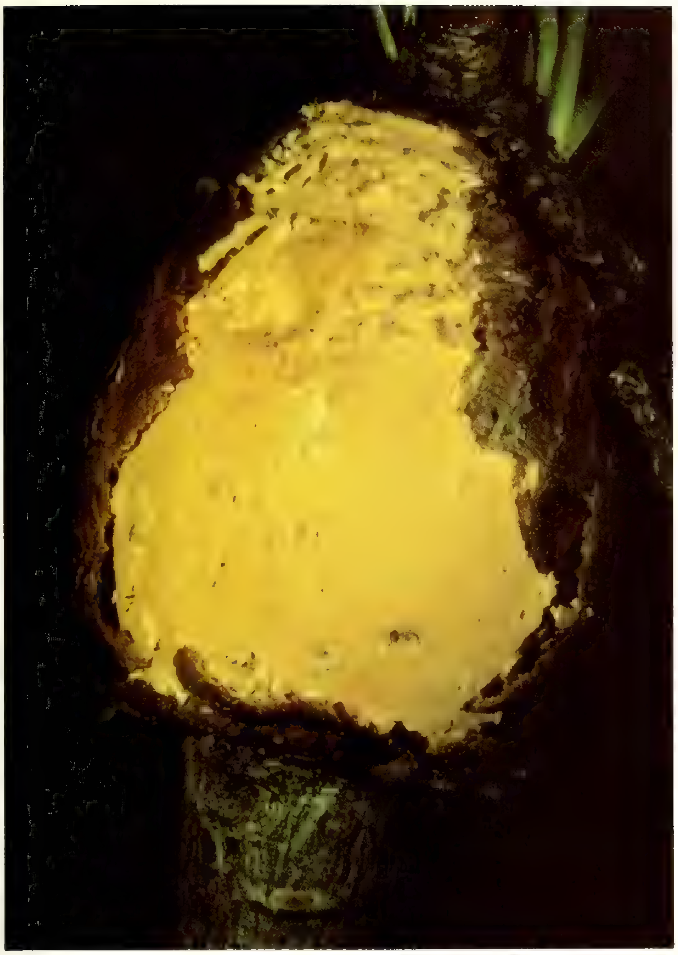


Figure 57-3. Gall with surface removed, exposing masses of spores.

Christmas tree plantings may lose value because of tree stunting, witches'-brooms, and dieback of tips.

Control

The most effective and economical control in nurseries is to remove the source of infecting spores. All gall-bearing pines within a half mile of the nursery should either be pruned free of all galls or felled. All gall-bearing seedlings should be destroyed. This sanitation measure should be done before galls sporulate in the spring.

Reducing the impact of this disease in infected plantations is difficult. Removal of gall-bearing branches probably would somewhat reduce the level of infection, but eradication of the fungus by removal of galls is not feasible, because of latent infections. A single application of maneb at the beginning of spore release has prevented infection of Scots pines in Christmas tree plantings in Pennsylvania.

Prevention is the best method for control in field plantings. If possible, obtain stock from a nursery that is free of the disease. Inspect trees for galls when planted and again the following two springs.

There is considerable variation in susceptibility to this pathogen among geographic sources of ponderosa pine. Some highly resistant sources have been identified. Use of this resistance could reduce damage.

Selected References

Peterson, Glenn W. Dispersal of aeciospores of *Peridermium harknessii* in central Nebraska. Phytopathology. 63: 170–172; 1973.

Walla, J. A.; Stack, R. W. Western gall rust in North Dakota. Plant Disease Reporter. 63: 432–433;1979.

Hiratsuka, Y. *Endocronartium*, a new genus for autoecious pine stem rusts. Canadian Journal of Botany. 47: 1493–1495; 1969.

Hiratsuka, Y.; Powell, J. M. Pine stem rusts of Canada. Canadian Forest. Serv. Tech. Rep. 4. Environment Canada; 1976. 83 p.

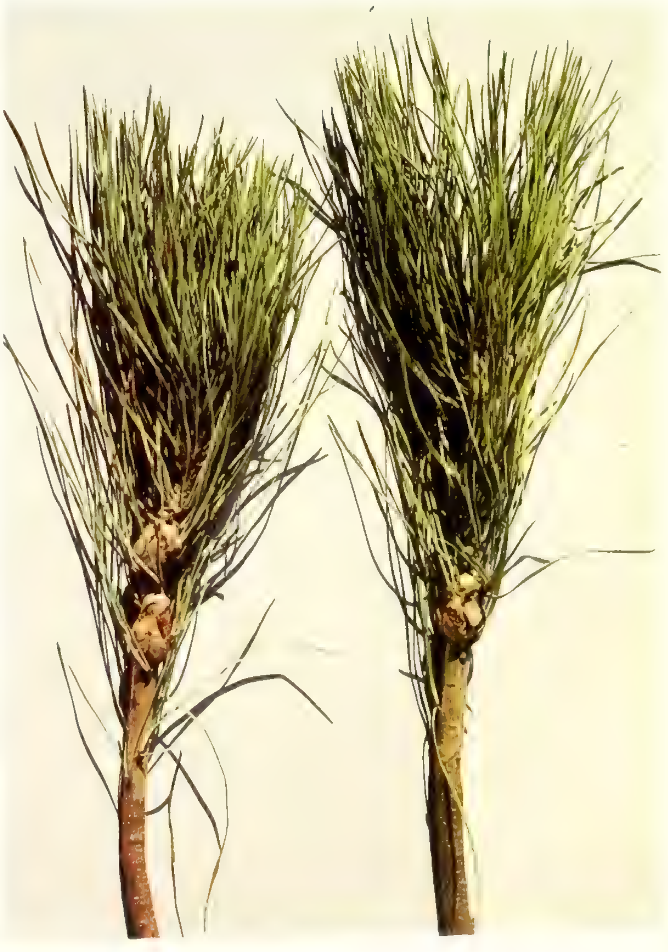


Figure 57-4. Galls on lodgepole pine seedlings infected with *E. harknessii.*

58. Diplodia Blight of Pines

Glenn W. Peterson and David W. Johnson

The fungus *Diplodia pinea* (*Sphaeropsis sapinea*) damages plantings of both exotic and native pine species in the United States. The effects of this disease are most severe in landscape, windbreak, and park plantings in the central and eastern United States. The fungus is seldom found in natural pine stands.

Hosts and Distribution

D. pinea is known to occur in 30 eastern and central States and in Hawaii and California (fig. 58–1). The fungus infects more than 20 pine species; it is frequently reported on Scots, red, ponderosa, and Mugo pines in the United States. It is a serious problem on Austrian pine, which, since the early 1900's, has been widely used in landscape, windbreak, and park plantings in the central and eastern United States.

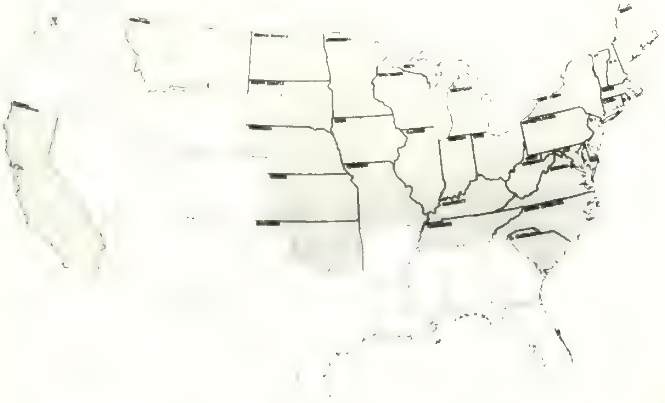


Figure 58-1. *Diplodia pinea* occurs in shaded states.

Symptoms and Signs

The most conspicuous symptom of Diplodia blight is brown, stunted new shoots with short, brown needles (fig. 58–2). Needles on infected new shoots often become discolored (tan, brown) while still encased in fascicle sheaths. Presence of resin droplets and one or a few very short needles are usually the first indications that a new shoot is infected. Entire new shoots are killed rapidly by the fungus.

New shoots throughout the crown may be infected, although damage is generally first evident in the lower crown. Usually infection varies considerably among major branches. Occasionally, after 2 or 3 successive years of infection, there is extensive killing of branches at the top of trees. Repeated infections reduce growth, deform trees, and ultimately kill them.

Seed cones of Austrian, ponderosa, and Scots pines are susceptible to *D. pinea* their second year, but not the first.

Disease Cycle

Small, black fruiting bodies (pycnidia), in which spores develop, form on needles, fascicle sheaths, scales of second-year seed cones, and bark. The fruiting bodies can be seen with a 10X hand lens. These black bodies, which erupt through the epidermis, usually are numerous at the base of needles (fig. 58–3) and on scales of second-year seed cones (fig. 58–4). Fruiting bodies are found easily on short needles of shoots infected the previous year, particularly on those that have turned ashen-gray and are easy to detach. When rainfall is above normal in late summer, unusually high numbers of pycnidia may develop on current-year needles and second-year cones. In most years, however, pycnidia are not numerous on these needles and cones until the following spring.

Highly moist conditions are needed for infection. Large numbers of spores (fig. 58–5), are dispersed only during rainy periods and high relative humidities are required for spores to germinate and for germ tubes to grow and penetrate needles and shoots. If rain is sparse when new shoots are highly susceptible, infection levels usually are very low. Once the fungus penetrates needles, however, tissues are rapidly destroyed, resulting in stunted shoots and needles.

New shoots of Austrian, ponderosa, and Scots pines are most susceptible during a 2–week period starting when buds begin to open, and continue to be susceptible until about mid-June. Symptoms on new shoots can readily be detected in late May; extent of infection can be effectively determined in late June or July.

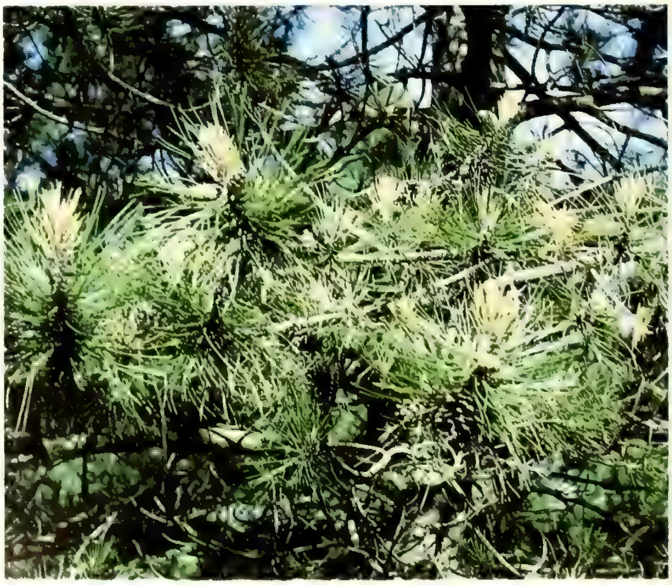


Figure 58-2. New shoots of Austrian pine killed by *D. pinea*.

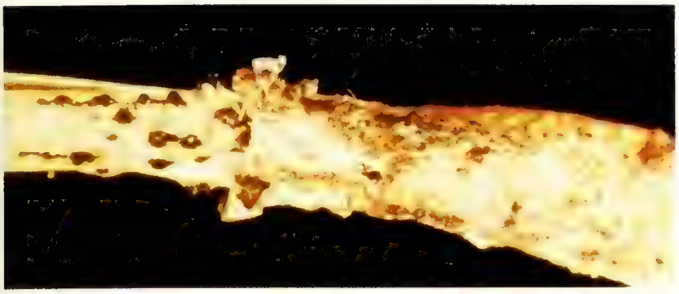


Figure 58-3. Fruiting bodies (pycnidia) of *D. pinea* at the base of Austrian pine needle.

Second-year seed cones are initially infected in late May. Numerous fruiting bodies develop on these cones, and the increased damage to older trees is probably related to this fungus buildup. Infected seed cones are often observed on otherwise healthy pines, which indicates that, on older pines, inoculum builds up on seed cones before new shoots are infected extensively.

Although unwounded new shoots can be infected, *D. pinea* infects both current-year and older tissues through wounds. *D. pinea* may severely damage trees wounded by hail or insects. Tissues wounded during pruning or shearing operations may also become infected. Wounded tissues remain vulnerable to *D. pinea* infection for several (at least 12) days.

Damage

Although pines of all ages are susceptible to *D. pinea*, damage is more severe in older plantings. In Great Plains windbreaks that were 20 to 22 years old, only a few pines were infected by *D. pinea*. Incidence and damage increased as the trees approached 30 years of age. Damage often is severe in pines that have an abundance of second-year seed cones.

D. pinea kills current-year shoots, major branches, and ultimately entire trees. Damage may be confined to the new shoots, particularly on trees with shoots infected for the first time. The fungus will infect older stem tissues, but the way this occurs is not always evident. Commonly, when new shoots are killed, only a small percentage of the subtended stem tissue and second-year needles show evidence of infection. On severely damaged trees, however, the fungus usually can be isolated from all segments of major bránches.

Control

Infection of new shoots can be reduced significantly by fungicide applied during the 2-week period when shoots are highly susceptible to infection. This period, approximately from the third week in April through the first week of May in eastern Nebraska, begins with the opening of buds. During this short period, two applications of 4-4-50 Bordeaux mixture [4 lb. copper sulfate, 4 lb. hydrated lime, and 50 gal. water] approximately 1 week apart are more effective than one application.

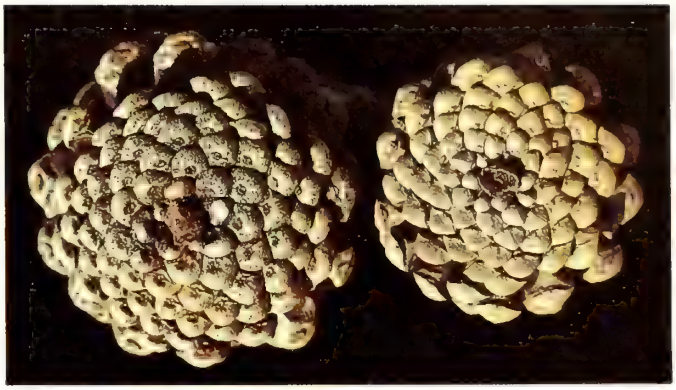


Figure 58-4. Pycnidia on an Austrian pine seed cone infected by *D. pinea* (left); uninfected cone (right).

Fungicide applied during late April and early May to protect new shoots does not prevent infection of seed cones. Thus, it would probably not be practical to try to reduce inoculum (spores) on seed cones with protective fungicides, because one or more additional fungicide applications would be required. Removal of infected branches may be justified on the basis of improving tree appearance, but probably will not reduce the amount of infection significantly.

Pruning or shearing in Christmas tree or other pine plantings should be avoided when conditions are favorable for infection because of danger of infection through wounds.

Young pines in plantings and pine seedlings in nursery beds usually become infected if they are located near old, cone-bearing pines. Either the old infected pines should be removed, or pine seedling beds or plantings should not be located near them.

Information on resistance to *D. pinea* among geographic seed sources of pine species is too limited for use in making recommendations for planting. However, Scots pine is often recommended for landscape plantings in eastern Nebraska because it is damaged less by *D. pinea* than the frequently planted Austrian and ponderosa pines.

Selected References

Peterson, Glenn W. Infection, epidemiology, and control of diplodia blight of Austrian, ponderosa, and Scots pines. Phytopathology. 67: 511–514; 1977.

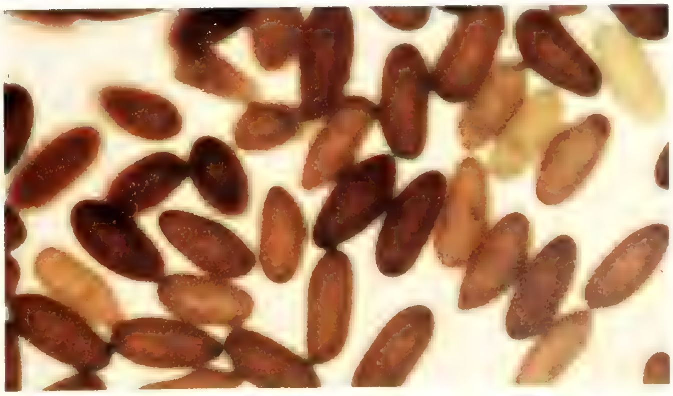


Figure 58-5. Spores of *D. pinea*.

59. Sirococcus Shoot Blight of Spruce

Kathryn Robbins and Edward M. Sharon

Sirococcus shoot blight, caused by the fungus *Sirococcus strobilinus*, affects conifers throughout the North Temperate Zone of North America and Europe. The disease chiefly affects current year's shoots.

Hosts and Distribution

Sirococcus shoot blight occurs in the United States and Canada on several species of pine, spruce, and hemlock. In the Great Plains, this disease occurs on blue spruce and Norway spruce in Kansas, and has been reported on blue spruce in South Dakota.

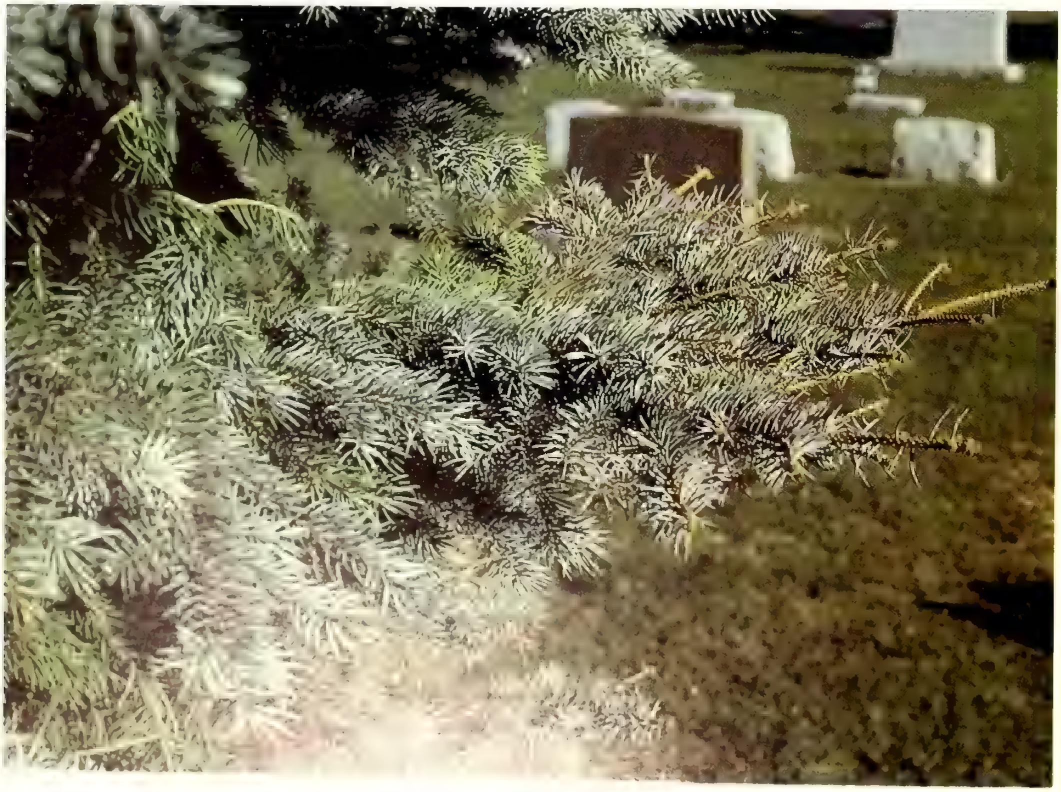
The disease is not common in the Great Plains, but its distribution and importance could increase if infected nursery stock is planted.

Symptoms and Signs

The fungus causes tip dieback and cankers on current year's growth. Foliage distal to the infection becomes chlorotic, dies, turns reddish-brown, and is shed (figs. 59–1, 59–2). Infected elongating shoots may curl and become hook-shaped.

Symptoms of this disease are similar to those of winter drying or frost injury. Shoots killed by *Sirococcus* are usually scattered, however, and fewer in number than the more uniform pattern of injury associated with winter drying or frost.

Small black fruiting bodies (pycnidia) form on bud scales and other parts of dead shoots (fig. 59–3). Spores (conidia) in these fruiting bodies are hyaline, fusiform, 2–celled, and approximately 2 by 12 μm.



Figures 59-1, 59-2. Infected blue spruce shoots from which foliage has been cast.

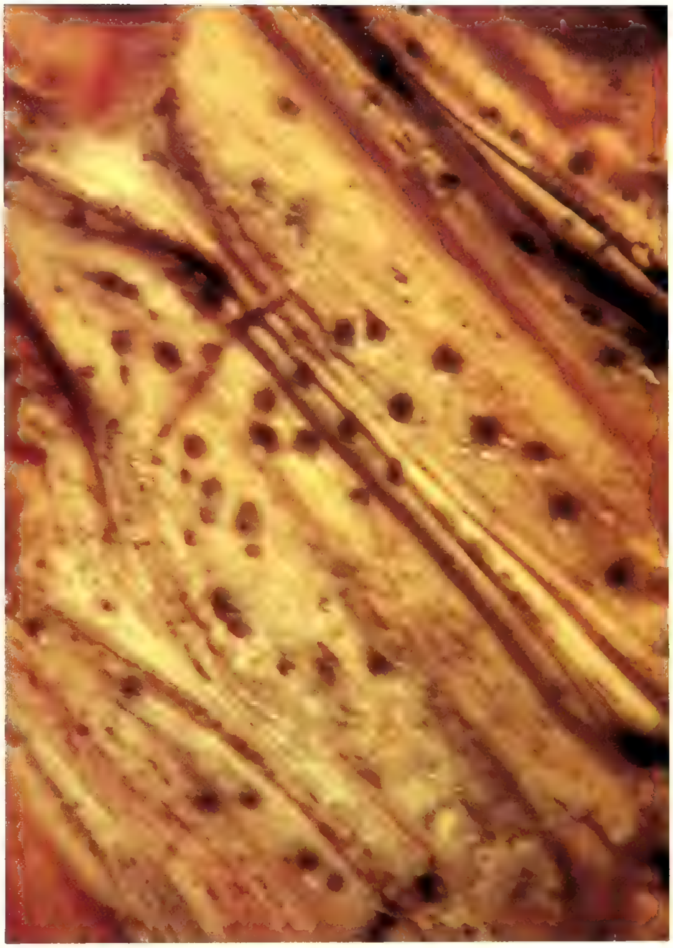


Figure 59-3. Fruiting bodies (pycnidia) of *Sirococcus strobilinus* on infected spruce stem.

Disease Cycle

Infection begins in needles and spreads into the stem to form a canker. The fungus grows within the succulent stem tissue but rarely into older wood. When infection occurs in the area of elongation, the restricted growth in the cankered area causes the shoot tip to curl over and form a crook.

As the canker develops, fruiting bodies that form on dead shoots produce large numbers of spores which are spread to nearby susceptible hosts by splashing rain or irrigation water. Under favorable conditions of high humidity, mild temperature, and low light, the spores germinate and infect current year's shoots.

Damage

Sirococcus shoot blight causes growth loss, stress, and an unsightly appearance of ornamental spruce, and can kill seedlings. In certain situations, the fungus may be seed-borne, causing damage to nursery and containerized seedlings.

Control

Cool, humid, shady conditions that favor infection should be avoided. If shoots on ornamental spruce become infected, they should be clipped off and destroyed to reduce the spread of spores. Infected nursery seedlings should be destroyed to prevent spread of the disease. Preventive chemical sprays developed for pines in California and in the Lake States may be effective on spruce nursery stock and ornamentals in the Great Plains.

Selected References

Nicholls, Thomas H.; Robbins, Kathryn. Sirococcus shoot blight. Forest Insect and Disease Leaflet 166. Washington, DC: U.S. Department of Agriculture, Forest Service; 1984. 6 p.

Shahin, Elias A.; Claflin, Larry E. The occurrence and distribution of Sirococcus shoot blight of spruce in Kansas. Plant Disease Reporter. 62: 648–650; 1978.

Smith, Richard S., Jr. Sirococcus tip dieback of *Pinus* spp. in California forest nurseries. Plant Disease Reporter. 57: 69–73; 1973.

Wall, R. E.; Magasi, L. P. Environmental factors affecting Sirococcus shoot blight of black spruce. Canadian Journal Forest Research 6: 448–452; 1976.

60. Cytospora Canker of Spruce

James A. Walla and Frederick J. Crowe

Cytospora canker, caused by the fungus *Valsa kunzei* (asexual stage *Cytospora kunzei*), is a destructive disease of spruce in the northern Great Plains. The fungus is synonymous with *Leucostoma kunzei* (asexual stage, *Leucocytospora kunzei*).

Hosts and Distribution

This pathogen attacks many species of spruce, including blue spruce and its cultivars, white spruce and its variety Black Hills spruce, Norway spruce, and Engelmann spruce. Cytospora canker also occurs on Douglas-fir. It has been reported throughout the upper Midwest and Northeast United States and adjacent Canada, and in the mountains of Colorado. In the Great Plains, it occurs in the prairie provinces of Canada, and in Montana and North and South Dakota.

Symptoms and Signs

Symptoms start on lower branches and spread to other branches laterally and upward in the tree (fig. 60–1). Needles on infected branches die and turn brown, and resin exudes from cankered areas. After a few months infected needles drop off, and white or light blue patches of resin become obvious on the dead bark of larger branches (fig. 60–2). There is little external evidence of the canker margin, but it can be found by exposing the inner bark. Infected bark tissue and cambium are brown in contrast to the normal light color of healthy tissue. The wood beneath infected bark is not discolored.

Asexual fruiting bodies (pycnidia) of the fungus develop in infected bark but are usually not visible on the bark surface. Superficial cuts in cankered bark will expose the small (1–3 mm dia.) black pycnidia (fig. 60–3). Orange spore masses or tendrils may exude from the pycnidia during wet weather. The spores (conidia) are hyaline, allantoid (sausage-shaped), 1-celled, and 4–6 by 1 μm.

Sexual fruiting bodies (perithecia) are sometimes associated with pycnidia, but they are usually on branches that have been dead for several years. Perithecia are smaller (0.2–0.6 mm dia.) than pycnidia and are grouped in a black stroma. Ascospores from

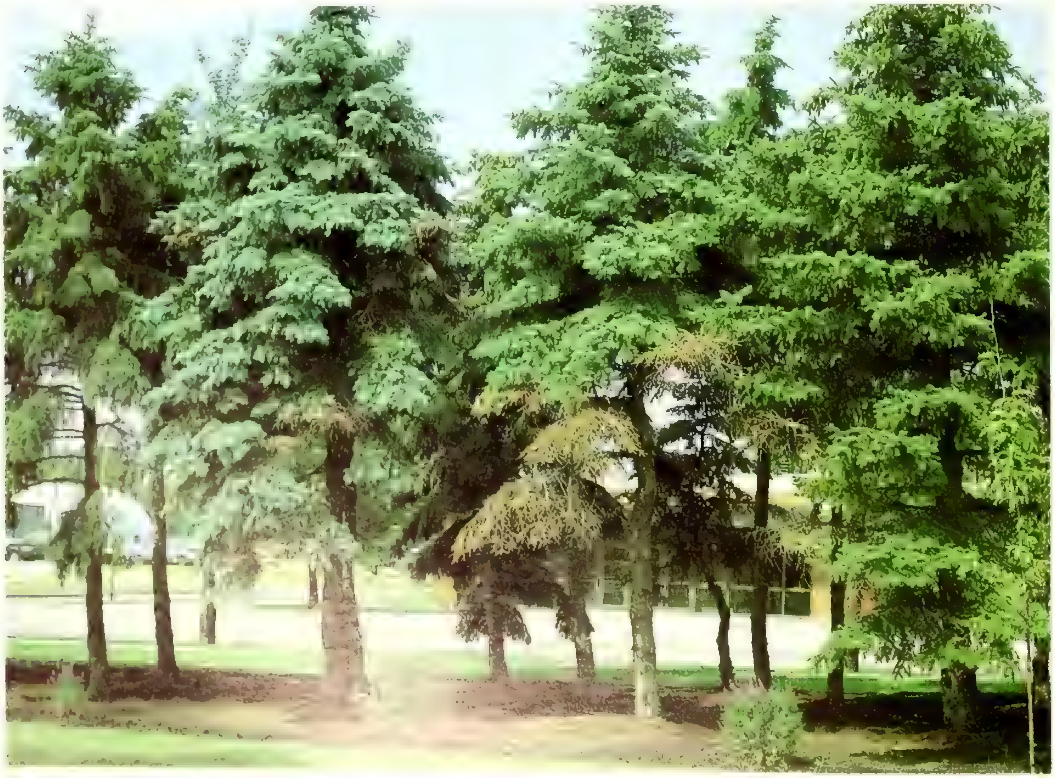


Figure 60-1. Colorado blue spruce trees with dying and dead lower branches killed by *Cytospora kunzei*.

perithecia are hyaline, allantoid, 1-celled, and 5–9 by 1.5 μm.

Because *Cytospora* will grow in bark killed by other agents, its presence alone does not mean the fungus killed the branches.

Disease Cycle

Spores from fruiting bodies on cankered branches are spread to the same or other trees by rainsplash, wind, insects, birds, and man. Infection occurs through wounds. The fungus grows and kills the bark, then expands until the entire branch is dead. Fruiting bodies form in infected bark. The fungus overwinters as fruiting bodies and mycelium in cankered bark.

Workers in Michigan found that conidia are released during all seasons except winter, and that ascospores are released only in the spring. They found that only the ascospore stage was infective. Other workers have found that the conidial stage is also infective, however.

Cytospora is often believed to damage only trees weakened by environmental stress, especially drought. Water stress increases susceptibility to infection, but apparently healthy trees also develop cankers when inoculated. Because Cytospora canker is rare on spruce in the southern Great Plains, other factors also may be involved.

Damage

Damage may occur in ornamental, plantation, or windbreak situations. The disease destroys the symmetry of spruce trees, reduces their effectiveness in blocking wind, snow, and noise, and in time, may kill them. Norway spruce is particularly prone to stem cankering in some areas, and thus is most likely to be killed. Blue spruce is more susceptible to damage from branch cankers than other species. Damage is most often seen on large trees, but may occur on young trees if they are planted on poor sites or are near infected large trees.

Control

Healthy trees are less susceptible to infection; thus they should be managed for optimum vigor. If possible, water and fertilize trees as needed. Reduce chances of infection by preventing wounds and by maintaining good air circulation around the trees. Do not bring infected branches into the area (such as spruce Christmas trees or branches). Blue and Norway spruce are most susceptible to damage, so consider planting other species or varieties if Cytospora canker is a threat.

If trees become infected, prune diseased branches and dispose of them as soon as possible. Cut back to the nearest living lateral beyond the canker or to the trunk. Pruning is best done in late winter before spores are released, but may be done during dry periods whenever dead branches are found. Disinfect pruning tools with rubbing alcohol after each cut, and apply a fungicidal wound dressing to all pruning wounds.

Protective fungicides have been recommended for control of Cytospora canker on spruce, but none are specifically labeled for this purpose. Information on the efficacy of the newer systemic fungicides against this disease is limited.

Selected References

Funk, A. Canker diseases of spruce. Pest Leaflet FPL 65. Canadian Forestry Service; 1978. 4 p.

Kamiri, Lewis K.; Laemmlen, Franklin F. Effects of drought-stress and wounding on Cytospora canker development on Colorado blue spruce. Journal of Arboriculture. 7: 113–116; 1981.

Schoeneweiss, Donald F. Drought predisposition to Cytospora canker in blue spruce. Plant Disease. 67: 383–385; 1983.

Waterman, Alma M. The relation of *Valsa kunzei* to cankers on conifers. Phytopathology. 45: 686–692; 1955.

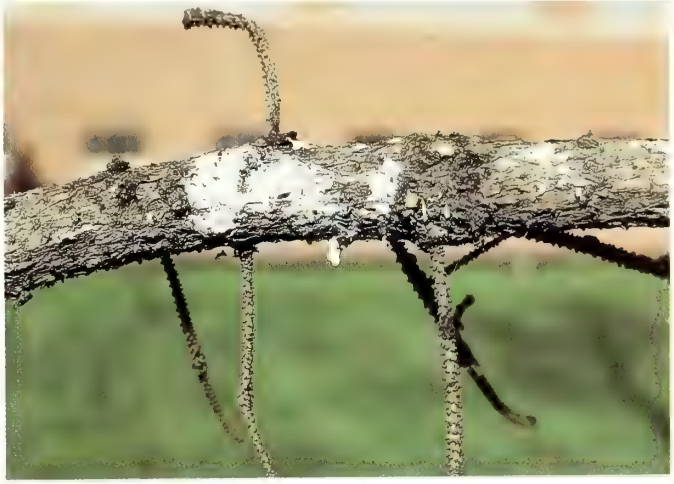
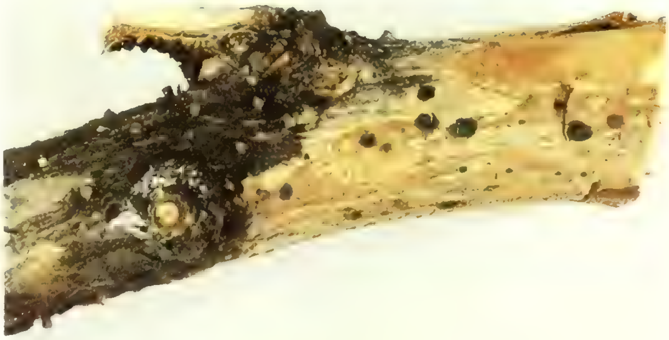


Figure 60-2. Resin exudes from cankered branches and is readily visible on dead bark a few months after infected needles are cast.

Figure 60-3. Black pycnidia of *C. kunzei* occur in brown cankered inner bark of infected spruce stems.



61. Antrodia Stem Decay of Eastern Redcedar

Edward M. Sharon and Jerry W. Riffle

Eastern redcedar has a wide distribution in the Great Plains, and is found on many soil types. Its hardiness and excellent survival on arid sites has made it a major component of field windbreaks in the Great Plains. *Antrodia juniperina* (referred to as *Daedalea juniperina* in older literature) causes stem decay in living eastern redcedar.

Hosts and Distribution

A. juniperina occurs on living or dead eastern redcedar in eight eastern States, plus Missouri, Oklahoma, Kansas, Nebraska, North Dakota, Colorado, Arizona, and Oregon. It also has been found on alligator, Utah, and one-seeded juniper in western United States. Its distribution is erratic in the Great Plains, and its occurrence is not correlated with the distribution or prevalence of its host.

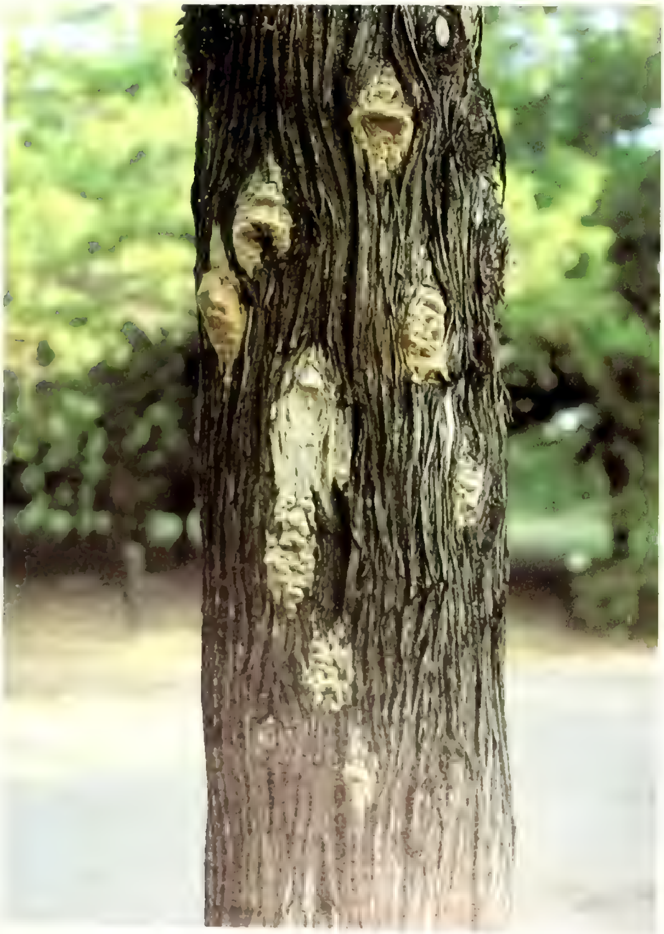


Figure 61-1. Sporocarps of ***Antrodia juniperina*** on stem of eastern redcedar, Woodward County, Oklahoma.

Symptoms and Signs

A. juniperina can be detected by the corky, sessile, sporocarps with daedaloid pore surfaces that form under dead branch stubs or along the callus margin of a wound (figs. 61–1, 61–2). The pores are large and angular, 12 to 18 per inch. The sporocarps are annual or perennial. The pileus of new sporocarps varies from light buff to cinnamon buff. It turns gray to black with weathering, and is indistinctly zonate. In the absence of sporocarps, check the ends of poorly healed branch stubs and stumps; thick, buff-colored mycelial felts develop in shrinkage cracks of decayed wood.

A. juniperina, a brown-rot fungus, utilize cellulose and other polysaccharides in wood, and primarily causes heart rot of affected stems. The residue left after decay is a brown crumbly mass. The brown-rot fungi do not produce extracellular phenol oxidases, and generally give negative oxidase tests on gallic and tannic acid medium or with gum guaiac solution.

Disease Cycle

Little information is available on the disease cycle of *A. juniperina*. Dead branches and wounds provide entry for the fungus. The fungus slowly invades and kills stem tissues, and a brown cubical rot develops.

The fungus can be cultured on malt agar and potato dextrose agar. Growth at 75°F is slow, reaching 14–15 mm in 7 days on malt agar. *Antrodia* and *Daedalea* appear similar in culture, but the lack of chlamydospores places *A. juniperina* in the genus *Antrodia* rather than in the genus *Daedalea*.

The basidiospores of *A. juniperina* are 6–7 μm long by 2–3 μm wide, narrowly ellipsoid, somewhat arcuate toward the apiculus, smooth, hyaline, and thin-walled.

Damage

Young trees are usually free from decay. A windbreak may begin to deteriorate, however, if infected eastern redcedars are a major component. Stems of infected trees may become hollow and break during windstorms because of extensive decay of wood.

Control

Tree losses caused by stem decay fungi can be reduced by the following measures:

1. Prevent wounds. In windbreaks and woodlots, limit the activities of animals, especially cattle, by fencing. Little can be done about the weather; however, after a storm prune broken limbs and remove jagged edges from limb and bole wounds to enhance callus formation.
2. Sanitize. Prune trees to remove dead, dying, or diseased portions of the tree.
3. Plan and implement improvement cuts. Cut and remove infected trees, and replant immediately to maintain effectiveness of windbreaks.

Selected References

Gilbertson, R. L. North American wood-rotting fungi that cause brown rots. Mycotaxon. 12: 372–416; 1981.

Lowe, Josiah L.; Gilbertson, Robert L. Synopsis of the Polyporaceae of the Western United States and Canada. Mycologia. 53: 474–511; 1961.

Murrill, William Alphonso. Polyporaceae. North American Flora. 9: 1–131; 1908.

Niemela, T.; Ryvarden, L. Studies in the Aphyllophorales of Africa. IV: *Antrodia juniperina*, new for East Africa. Transactions of the British Mycological Society. 65(2): 427–432; 1975.

Overholts, Lee Oras. Polyporaceae of the United States, Alaska, and Canada. Ann. Arbor: Univ. Michigan Press; 1953. 468 p.

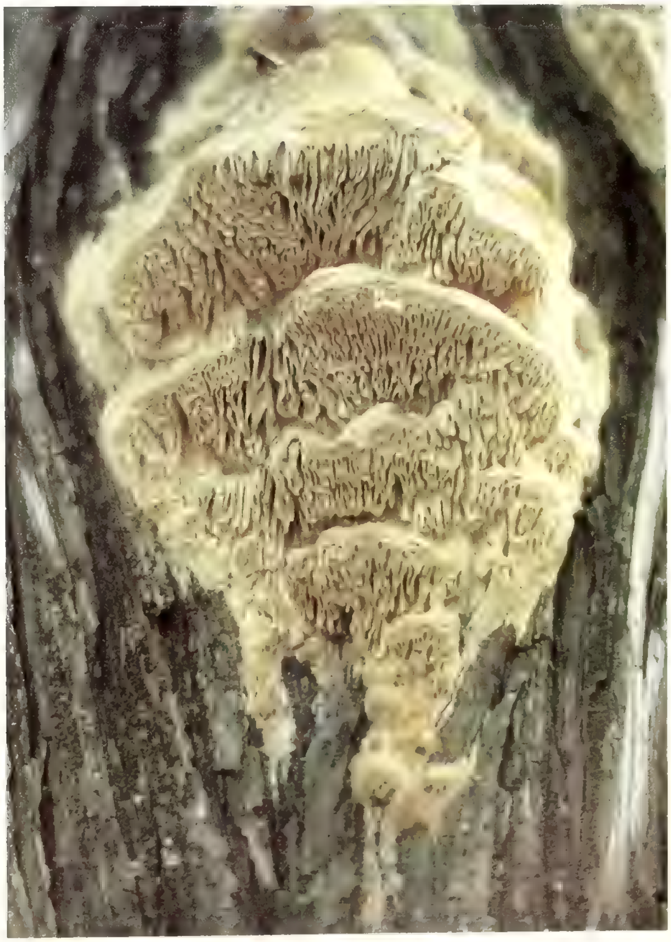


Figure 61-2. Enlarged view of daedaloid pore surface.

62. Gymnosporangium Rusts of Junipers

James A. Walla and Jerry W. Riffle

Gymnosporangium species that infect junipers are commonly called "cedar-apple rusts."

Hosts and Distribution

Several *Gymnosporangium* species occur in the Great Plains (table 62–1). These species must alternately infect two hosts to complete their life cycle. In the Great Plains, the telial stage is always on juniper species and the aecial stage is always on rosaceous species.

Symptoms and Signs

Symptoms on junipers vary, depending on the rust species involved. They include small lesions on needles, globular branch galls (fig. 62–1), fusiform stem swellings (fig. 62–2), gall-like branch knots (fig. 62–3), or witches'-brooms (fig. 62–4). During wet periods, especially in spring, one to many orange, gelatinous, fingerlike, telial horns extrude from these structures.

Symptoms on rosaceous hosts are rust lesions on leaves, fruit, petioles, or new twigs. Yellow to orange lesions containing black pimple-like pycnia develop first (fig. 62–5); then tubelike aecia form in the same lesions.

Disease Cycle

After spring rains (March-June), telial horns extrude from each lesion, gall, swelling, or broom on junipers. Teliospores in the horns germinate to produce basidiospores, which are carried by wind or insects to nearby rosaceous hosts. After infection of susceptible host tissue by basidiospores, pycnia develop in yellow to orange lesions, followed by production of aecia. Aeciospores are wind-blown to junipers in the same growing season from late spring to early fall, depending on species of rust fungus. After infection of the juniper, galls or other structures form. The orange gelatinous telial horns appear on them either the following spring or one year later. The cycle is then repeated.

Damage

Damage due to massive infection of rosaceous hosts can influence yield (current and following year), fruit quality, vigor, and esthetic value. Apples are particularly subject to these effects.

Damage to junipers is usually slight. If massive infection occurs, reduction in vigor, growth rate, and esthetic value can result. Rust fungi that cause either stem swellings or knotlike branch galls kill branches above the infected points. Fungi that cause witches'- brooms can deform trees.

Control

Several control methods are available, depending on individual situations. Similar control methods should be

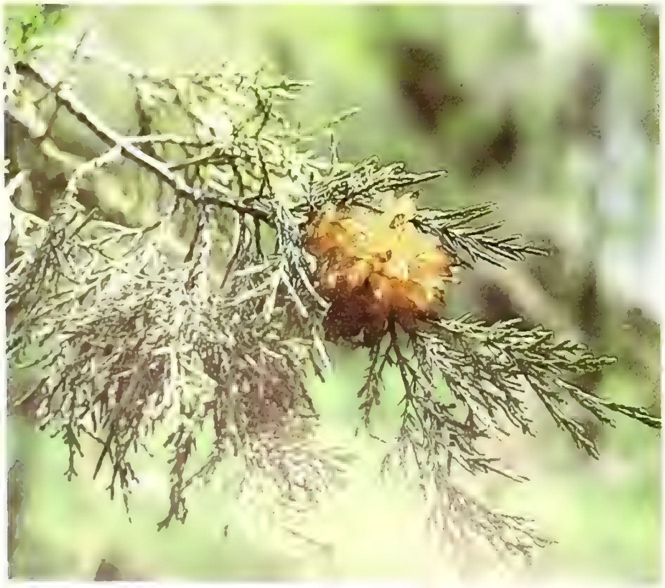


Figure 62-1. Orange telial horns of [illegible] species extruding from a branch gall on [illegible]

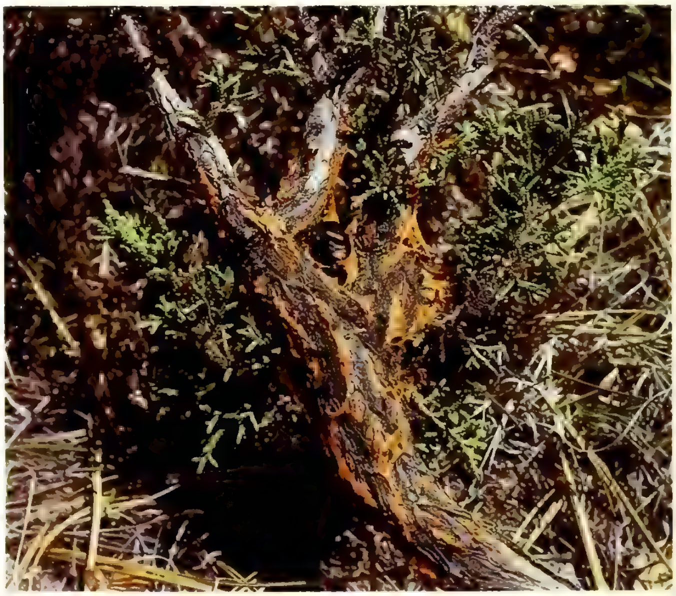


Figure 62-2. Dry orange telial masses of a *Gymnosporangium* species extruding from a branch with a stem swelling.

Table 62-1. Some *Gymnosporangium* species in the Great Plains.

Species of rust fungus	Great Plains distribution	Symptoms on junipers	Major aecial hosts[1]
juniperi-virginianae	Widespread	Branch gall	Apple, crabapple
connersii	Northern Plains	Branch gall	Hawthorn
corniculans	Northern Plains	Branch gall	Juneberry
trachysorum	Southern Plains	Branch gall	Hawthorn
bethelii	All except Texas	Gall-like branch knots	Hawthorn
globosum	Widespread	Gall-like branch knots	Hawthorn
nelsonii	Western and Northern Plains	Gall-like woody knots or no symptoms	Juneberry
clavipes	Widespread	Stem swellings	Many Rosaceae
gracile	Texas	Stem swellings, Witches'-brooms	Juneberry
nidus-avis	Widespread	Stem swellings, Witches'-brooms	Juneberry
clavariforme	Widespread	Stem swellings Witches'-brooms	Juneberry
exiguum	Southern Plains	Foliar lesions	Hawthorn

[1] Other Rosaceae may be aecial hosts for some of these rusts.

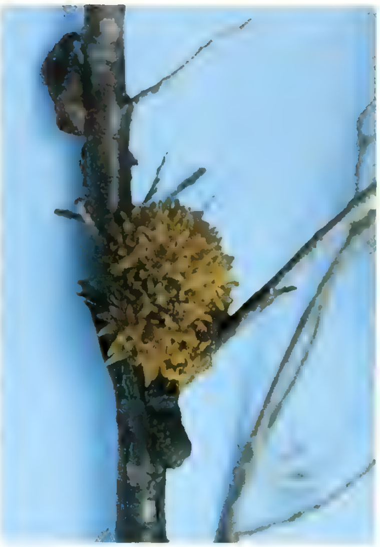


Figure 62-3. Orange telial horns of a *Gymnosporangium* species extruding from a gall-like branch knot on eastern redcedar.

effective for all Gymnosporangium rusts with similar life cycles.

Two hosts are required to complete the life cycle; eradication of one host from the vicinity will eliminate new infections. A 2-mile separation usually will minimize rust infections.

In some situations, control may be achieved by pruning affected parts from the *Juniperus* host. Do not plant susceptible varieties near alternate hosts. Susceptibility of available varieties of both hosts has been determined for some Gymnosporangium rusts.

Several preventative fungicides are registered for control of some rust fungi on both hosts. They may be applied on orchard and ornamental trees. The rosaceous host must be protected in the spring, starting before flowering and continuing until telial horns on juniper become inactive (usually 4 to 6 weeks). The *Juniperus* host must be protected when aecia have formed on the corresponding rosaceous host.

Selected References

Himelick, E. B.; Neely, Dan. Juniper hosts of cedar-apple and cedar-hawthorne rust. Plant Disease Reporter. 44: 109–112; 1960.

Kern, F. D. A revised taxonomic account of *Gymnosporangium*. University Park: Pennsylvania State University Press; 1973. 134 p.

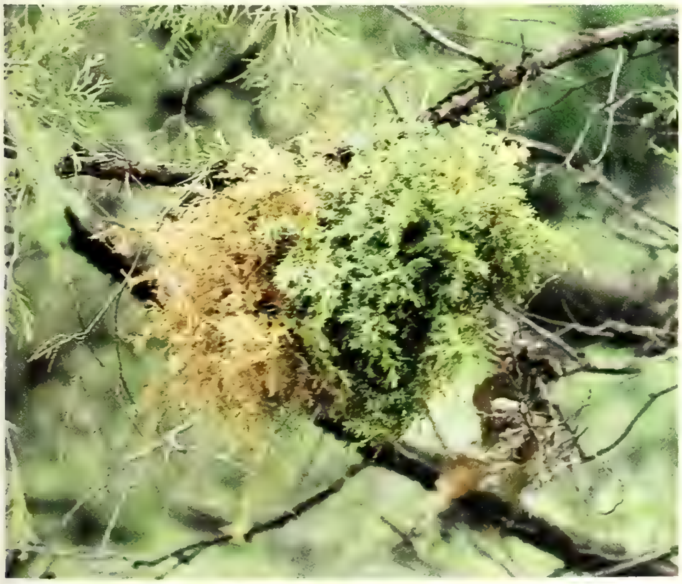


Figure 62-4. Witches'-broom on Rocky Mountain juniper caused by *G. nidus-avis*.

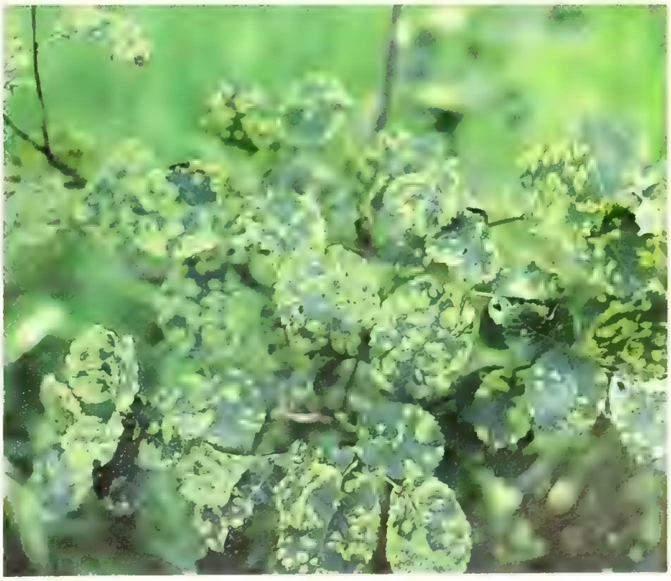


Figure 62-5. Rust lesions on juneberry leaves caused by *G. nidus-avis*.

63. Pine Wilt Disease

Jerry W. Riffle and Frederick J. Crowe

The pine wood nematode, *Bursaphelenchus xylophilus*, causes a disease of pines called pine wilt. This nematode is unusual, compared to other plant-parasitic nematodes, because it is a pathogen in above-ground parts of trees, is transmitted by insects, and does not enter the soil. *B. xylophilus* was first reported in the United States in 1931 in logs of longleaf pine. However, it was not recognized as a potential pathogen of pines in this country until 1979 when it was found associated with dying Scots and Austrian pines in Columbia, Missouri.

Hosts and Distribution

Twenty-two species of *Pinus*, one species of *Abies* and *Pseudotsuga*, and two each of *Larix*, *Picea*, and *Cedrus* are known hosts of the pine wood nematode in the United States. The ability of this nematode to kill native North American pines growing in forests has not been established, but evidence suggests that it can kill exotic pines such as Scots, Austrian, and Japanese black pines in the United States, particularly on off-site, high-stress locations. Most pine mortality has occurred in landscape plantings, but the nematode also has caused mortality in windbreaks, Christmas tree, and recreational plantings. Scots pine, an important landscape and popular Christmas tree species, is the most commonly reported host. In the Great Plains, *B. xylophilus* has been found on Scots, Japanese black, Austrian, eastern white, and loblolly pines. Greenhouse inoculation tests show that the five species most susceptible to *B. xylophilus* are jack, shortleaf, Monterey, sugar, and Scots pines.

Nationally, *B. xylophilus* has been found in 34 States, including all states in the Great Plains except North Dakota. However, typical symptoms of pine wilt have not been observed throughout the geographical range of *B. xylophilus*. The nematode can reproduce on fungi associated with dead, stressed, and live pines, and thus can be found in pines killed by other agents. The widespread distribution and host range of this nematode suggest it is endemic to the United States.

Symptoms and Signs

The first symptom of pine wilt is a marked reduction in flow of oleoresin that occurs before external symptoms are apparent. Transpiration from foliage decreases, then stops 3 to 4 weeks after infection. Foliage rapidly yellows and browns as sapwood moisture decreases (fig. 63–1). Needles show definite wilt only in long, soft needled species such as white pine. Foliar symptoms may progress uniformly through the tree or branch by branch, largely depending on the size of the tree and the season of death. Trees may die from midsummer to late fall or from late winter to late spring. The rapid death contrasts with the slow decline caused by pathogenic fungi such as *Diplodia pinea*, or by unfavorable environmental conditions.

Disease Cycle

The biology of *B. xylophilus* and basic information on the disease cycle have been determined by scientists in Japan where pine wilt has been a serious problem for many years. The cerambycid beetle *Monochamus alternatus* is the principal vector that transmits *B. xylophilus* to native Japanese pines. Adult beetles infested with *B. xylophilus* emerge from dead pines in May and June, fly to healthy pine trees, and begin maturation feeding on phloem of young pine shoots (fig. 63–2). Immature nematodes leave the tracheae of the beetle, enter feeding wounds, molt to the adult stage, mate, and reproduce rapidly in the resin canals of the pine host during the

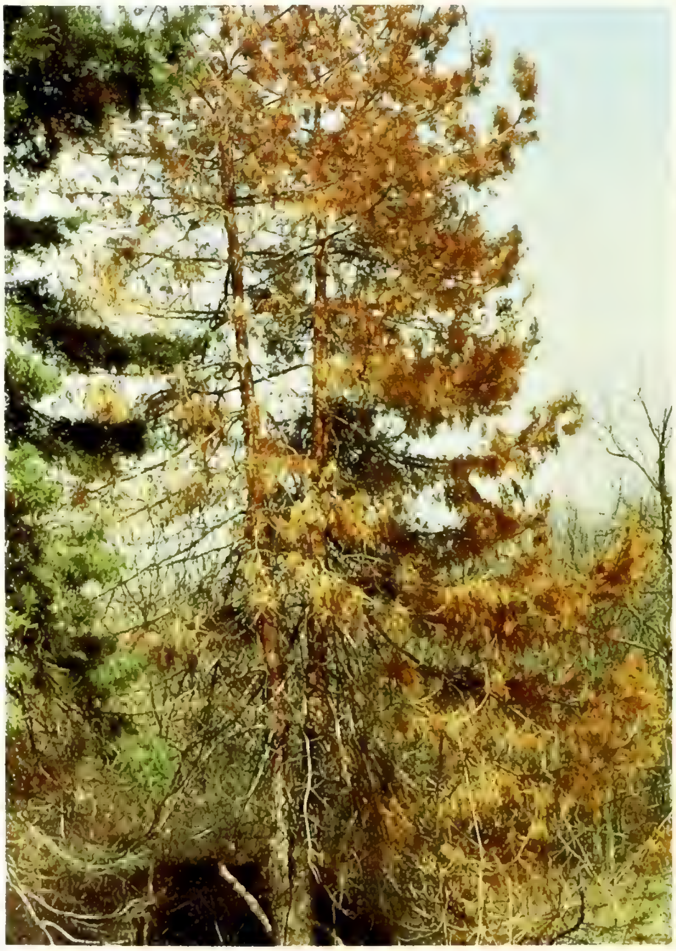


Figure 63-1. Scots pine tree showing brown foliage symptoms of pine wilt disease.

propagation phase of the life cycle (fig. 63–3). Under optimum conditions, growth of nematodes from eggs to adults is completed in 5 days. Within 4 to 5 weeks, infected pines exhibit reduced oleoresin flow and transpiration, and large numbers of nematodes are present throughout trees as wilting and yellowing of foliage become noticeable.

Trees die within 3 months after becoming infected. Nematodes continue to reproduce for several months on fungi, principally the blue stain fungi, that invade the dead trees. Nematode development then converts to a dispersal phase as the wood dries. During this phase, the nematodes molt from second-stage propagative larvae to third-stage dispersal larvae. These larvae contain high levels of lipids, are resistant to adverse environmental conditions, and do not feed. During early spring these larvae molt from the dispersal stage to the fourth larval stage, called dauer larvae. Cerambycid beetles are attracted to dying trees and oviposit in them. The cerambycid larvae, known as pine sawyers,bore into the wood, overwinter, and pupate in the spring. Dauer larvae of *B. xylophilus* enter adult beetles prior to their emergence. These beetles transmit the nematodes to healthy trees when they begin maturation feeding.

The development of pine wilt differs in the United States. *B. xylophilus* is carried by *Monochamus carolinensis, M. mutator*, M. *notatus, M. obtusus, M. scutellatus*,and *M. titillator* in the eastern United States. The principal vector in pine wilt appears to be *M. carolinensis* (fig. 63–4). Investigations in Minnesota, Wisconsin, and Iowa have shown that *B. xylophilus* is transmitted to dying trees and cut timber of native pine species by *M. carolinensis, M. scutellatus*, and *M. mutator* during oviposition. Thus *B. xylophilus* may be present in conifers dying as a result of any cause. This pattern of attack may explain the association of *B. xylophilus* with trees in the north-central region that are stressed by various pathogens and insects, but lack typical symptoms of pine wilt.

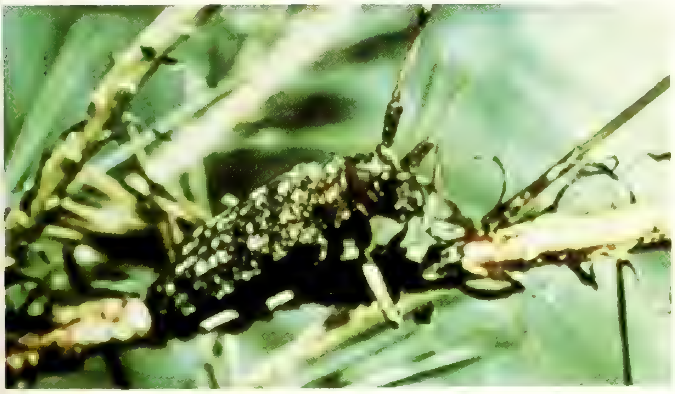
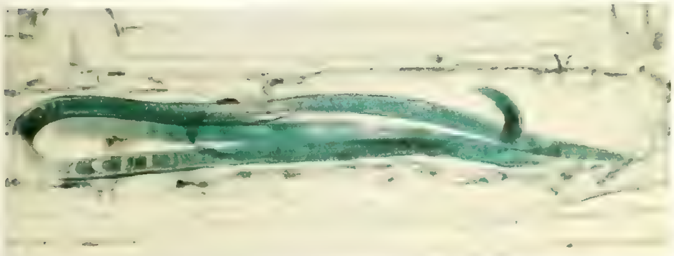


Figure 63-2. Maturation feeding by *M. alternatus* on Japanese black pine.

Figure 63-3. Longitudinal section of pine wood showing pinewood nematodes in pine resin canals.



Damage

Pine wilt poses a potential threat to susceptible species of pines, especially to Scots pines, growing on poor sites. Pine wilt is not a significant problem in native pine forests.

Control

Control measures are not justified in forest situations. In established landscapes, windbreaks, and Christmas tree plantings, destroy recently infected trees by cutting and burning to eliminate the breeding habitat of beetle vectors and to kill larvae and pupae of vectors before they emerge. Control known pathogens and insect pests of pines to avoid stressing trees and attracting vectors that could transmit nematodes to stressed trees during oviposition. In high value areas, keep trees well pruned of dead and diseased branches.

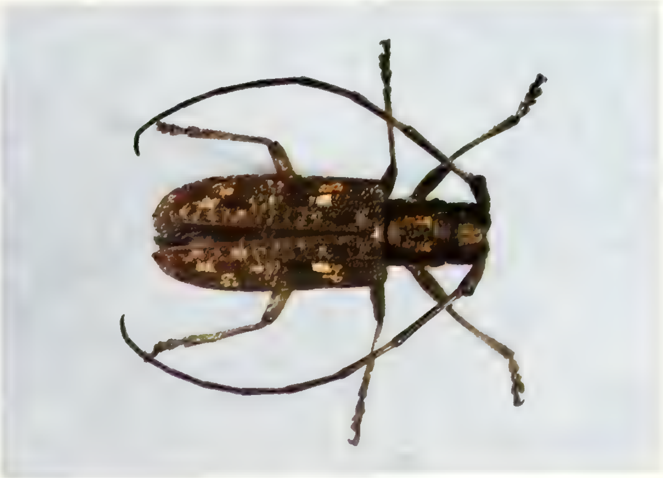
Selected References

Kondo, Eizo; Foudin, Arnold; Linit, Marc; Smith, Mike; Bolla, Robert; Winter, Rudy; Dropkin, Victor. Pine wilt disease—nematological, entomological, and biochemical investigations. Publication SR 282. Columbia: University of Missouri Agricultural Experiment Station; 1982. 56 p.

Malek, Richard B.; Appleby, James E. Epidemiology of pine wilt in Illinois. Plant Disease. 68: 180–186; 1984.

Wingfield, M. J.; Blanchette, R. A.; Nicholls, T. H. Is the pine wood nematode an important pathogen in the United States? Journal of Forestry. 82: 232–235; 1984.

Figure 63-4. *Monochamus carolinensis* is the principal vector of the pinewood nematode in the United States.



64. Root Lesion Nematodes in Junipers and Pines

Glenn W. Peterson and Jerry W. Riffle

A survey in Great Plains tree nurseries in 1960 revealed that conifer seedlings were more commonly damaged by root lesion nematodes than by any other group of nematodes.

Hosts and Distribution

The root lesion nematode encountered most frequently in the 1960 survey was *Pratylenchus penetrans*. This nematode was found in the roots of seedlings in central and eastern Nebraska nurseries.

P. penetrans has a wide host range, which includes field crops as well as trees. In central Nebraska, this nematode was found in roots of eastern redcedar, Rocky Mountain juniper, white spruce, blue spruce, Austrian pine, and ponderosa pine.

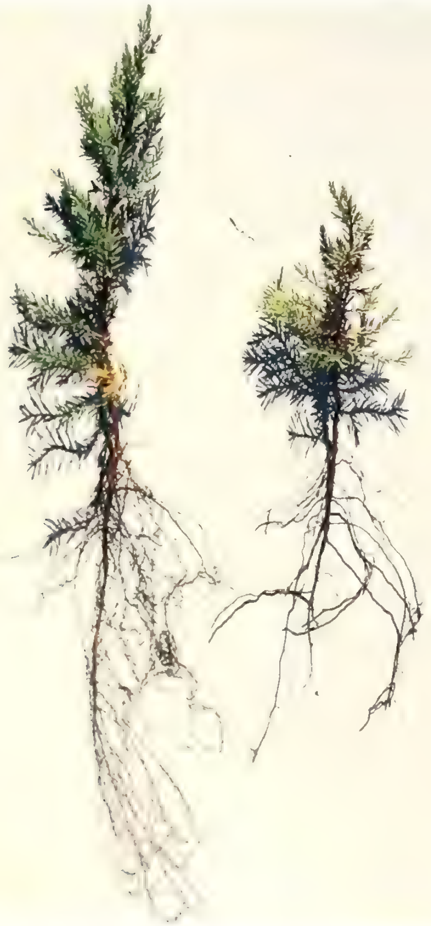


Figure 64-1. Eastern redcedar [illegible] root lesion nematodes; left is non-[illegible] [illegible].

Symptoms and Signs

Reduced growth of seedlings is the most obvious symptom in nurseries (fig. 64–1). See Article 49 for general symptoms on infected seedlings. Commonly, stunted seedlings are in irregular patches. When nursery soil infested with root lesion nematodes is fumigated, there are occasional areas where fumigation is not complete (due to misses or torn plastic sheets); infected, low vigor seedlings can often be found in these areas (fig. 64–2).

Infected seedlings that are stunted have a reduced root system, and usually develop new, fleshy roots in response to the depleted root system. These fleshy roots are lighter colored and larger in diameter than adjacent older roots. A check for the presence of root lesion nematodes by standard extraction procedures is best done on these fleshy roots.

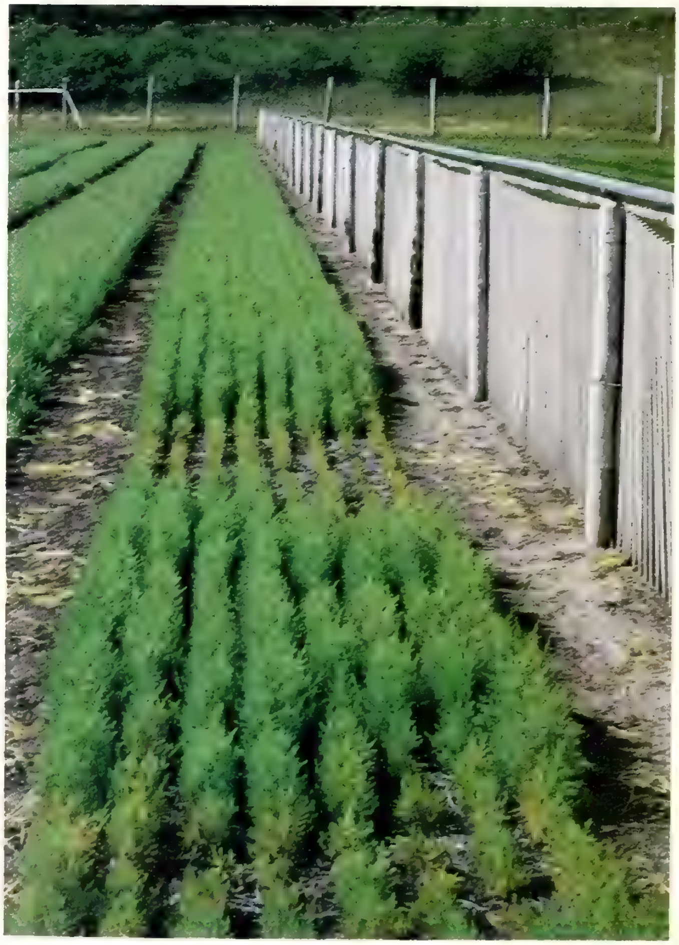


Figure 64-2. Damage to eastern redcedar seedlings where soil fumigation not complete.

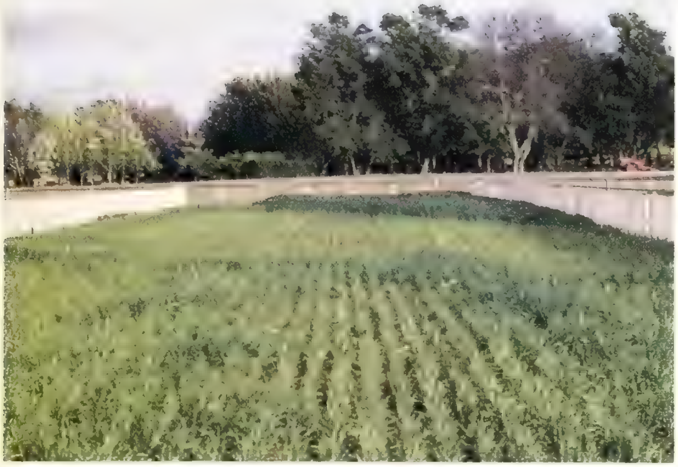


Figure 64-3. Damage to an oat cover crop in a nursery block infested with root lesion nematodes; healthy oats in non-infested area (background).

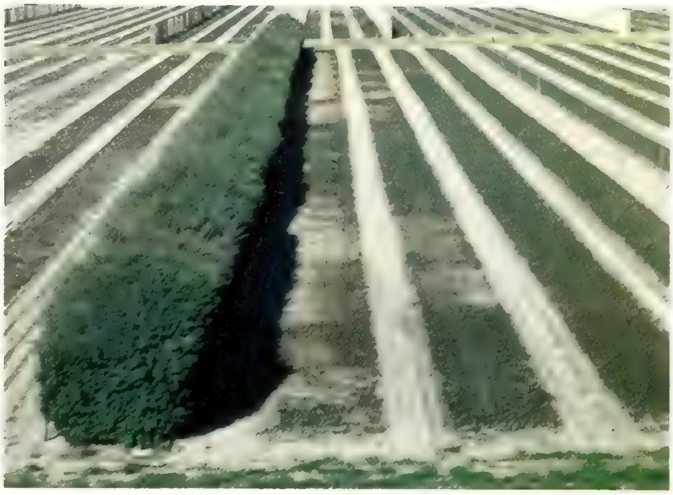


Figure 64-4. Eastern redcedar seedling damage in beds adjacent to windbreak of eastern redcedar infected with root lesion nematodes.

Older, established trees that are growing in soil infested with root lesion nematodes may not show external evidence of infection, even though their roots are infected.

Disease Cycle

Root lesion nematodes are soil borne. They enter and complete a part of their life cycle inside feeder roots. They persist in the soil, where they overwinter even in northern nurseries. Thus the source of infection is nematodes present in the soil when seedlings are established. Nematode populations can increase on some cover crops (fig. 64–3).

Damage

Root lesion nematodes feed and move within roots, thereby damaging roots and reducing the growth of seedlings. Established pines, junipers, and spruce in nursery windbreaks, landscapes, and field plantings are also subject to infection, but damage is not obvious. In a central Nebraska nursery root lesion nematodes were numerous in soil beneath eastern redcedar windbreaks. Although damage to windbreak trees was not obvious; there was extensive damage to seedlings in adjacent nursery beds (fig. 64–4).

Control

Damage by root lesion nematodes can be reduced by treating nursery soil with fumigants such as methyl bromide (fig. 64–5). Fumigation drastically reduces the population of nematodes, but it does not completely eradicate them from the soil. Seedlings in the central Great Plains can be grown in fumigated soil for 2 years without significant damage, but third-year seedlings are likely to be severely damaged.

In nurseries, damage from root lesion nematodes can be reduced by soil fumigation, by use of cover crops that are resistant, and by use of non-susceptible trees in nursery windbreaks.

Selected References

Dunn, R. A.; Mai, W. F. Reproduction of *Pratylenchus penetrans* in roots of seven cover crop species in greenhouse experiments. Plant Disease Reporter. 57: 728–730; 1973.

Peterson, Glenn W. Response of ponderosa pine seedlings to soil fumigants. Plant Disease Reporter. 54: 572–575; 1970.

Peterson, Glenn W. Root lesion nematode infestation and control in a Plains forest tree nursery. Research Note RM–75. Fort Collins CO: U.S.Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1962. 2 p.

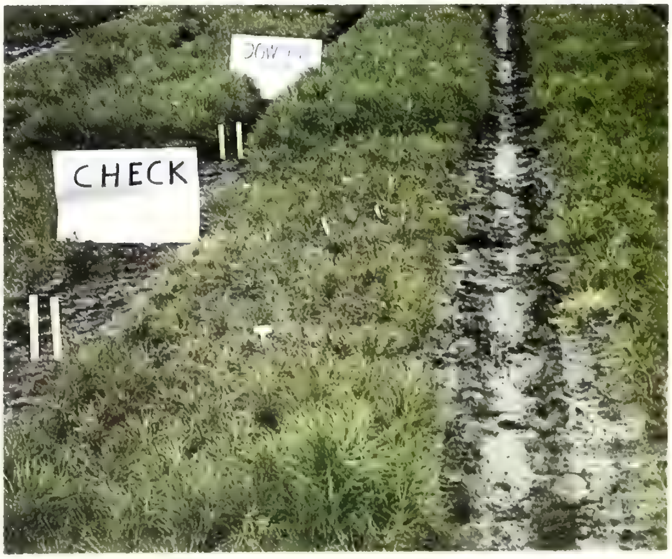


Figure 64-5. Control of root lesion nematodes by fumigation of soil with methyl bromide.

GLOSSARY

ACERVULUS (LI)—a small subcuticular or subepidermal cushionlike asexual fruiting body, without a covering of fungus tissue, producing conidia in a moist mass which escapes through a break in the host tissue.

AECIOSPORE—one of several kinds of spores produced by a rust fungus. Formed in and released from a fruiting structure called an aecium.

AECIUM (IA)—a cuplike fruiting structure produced by certain rusts, in which chains of spores (aeciospores) are developed.

AGAR—a substance from certain red algae used to make culture media into gels upon which microorganisms are grown.

ALLANTOID—slightly curved with rounded ends; sausage-like in form.

ALPHA-SPORE—a fertile spore of the asexual stage of the Diaporthaceae (*Phomopsis*) that is fusoid to oblong and biguttulate; BETA-SPORE, usually hooked shaped, is produced in addition.

ALTERNATE HOST—one or the other of the two unlike host plants parasitized by a heteroecious fungus such as a typical rust fungus, i.e., either the juniper or apple host of the cedar-apple rust fungus.

ANAEROBE—A microorganism that can live and grow where there is no free oxygen.

ANAMORPH—The asexual form of a fungus (e.g. that characterized by conidiomata).

ANNULUS—a ring-like partial veil around the stem of a fruiting body after expansion of the pileus (cap).

ANTHRACNOSE—a type of plant disease which typically is a leaf and twig blight. Common on many hardwoods.

APOTHECIUM(IA)—a cup or saucerlike sexual fruiting body which produces ascospores.

ASCOSPORES—a spore produced in an ascus (see ascus).

ASCUS(I)—a sac-like cell of the perfect stage of the Ascomycetes in which ascospores—usually eight—are produced.

ASEXUAL STAGE—a stage in the life cycle of a fungus in which spores are produced without a previous sexual fusion; also called imperfect stage.

BASIDIOSPORE—the spore produced by the sexual stage of the Basidiomycetes.

BASIDIUM(IA)—a cell, usually terminal, in which nuclear fusion and meiosis occur and each of the four haploid nuclei pass into one of four forming spores.

BETA-SPORE—see alpha-spore.

BLIGHT—a general term for a plant disease causing rapid death or dieback.

BORDEAUX MIXTURE—a fungicidal spray used for controlling plant diseases. A common mixture is 4-4-50, which means 4 lbs. copper sulfate, 4 lbs. lime, and 50 gal. water. **BROOM**—an abnormally dense mass of host branches and foliage in which the typical host growth pattern [illegible]

BROWN ROT—[illegible] that degrade cellulose, do not [illegible] loxidases, common and gen[illegible]

CANKER—a definite relatively localized necrotic lesion primarily of the bark and cambium.

CARPOGIUM(IA)—the female sex organ.

CHLOROSIS—an abnormal yellowing of the foliage.

CHLOROTHALONIL—a relatively broad spectrum organic fungicide. A foliar fungicide.

CHLOROTIC—abnormally yellow.

CLEISTOTHECIUM(IA)—a closed fruiting body, without an ostiole, containing asci.

CONIDIOMA(MATA)—A specialized multi-hyphal, conidia-bearing structure.

CONIDIOPHORE—a specialized hypha bearing conidia.

CONIDIUM(IA)—a spore formed asexually, usually at the tip or side of a hypha.

CONK—a type of fruiting (spore-forming) structure formed by certain fungi, usually wood rotters (Basidiomycetes). It is often bracket-like, and is referred to as "sporocarp," "sporophore," "fruiting body," "carpophore," "fructification," "basidiocarp," "punk," "bracket," and "shelf."

CONTEXT (OF SPOROCARP)—the inner tissue of the pileus (cap), i.e., the tissue lying between the upper surface and the tube or pore layer. The context often is designated as the "trama" of the pileus.

COREMIUM(IA)—a specialized multi-hyphal structure composed of a compact group of erect and sometimes fused conidiophores bearing conidia at the apex or on both apex and sides.

COVER CROP—a crop, natural or introduced, that is grown alternately with the main crop. Used to prevent erosion and improve soil characteristics.

CULTIVAR—an assemblage of cultivated individuals distinguished by any useful, reproducible character.

CUTTING—detached portion of stem or other plant part which, when rooted, produces a whole plant.

DAEDALOID-PORES—with elongated and sinuous mouths.

DECAY—the decomposition of plant tissue by fungi and other microorganisms.

DEFOLIATION—loss of current year's or past years' foliage.

DIEBACK—the death of parts of a tree or plant usually from the top downward.

DISEASE—unfavorable change of the function or form of a plant from normal, caused by a pathogenic agent or unfavorable environment.

DISEASE CYCLE—the chain of events in the development of a disease.

EFFUSED-REFLEXED—spread out over a substratum and turned back at the margin to form a pileus (cap).

EPIDEMIC—pertaining to a disease which has built up rapidly and reached injurious levels.

EPIDERMIS—the outermost layer of cells on the primary plant body.

EPIPHYTE—a plant that grows on another plant but is not a parasite and produces its own food by photosynthesis.

EXUDATE—matter which oozes out or is secreted.

FACULTATIVE PARASITE—an organism which is normally saprophytic but which is capable of living as a parasite only when unfavorable conditions predispose the host so that it is unusually susceptible.

FACULTATIVE SAPROPHYTE—an organism which is normally parasitic but which is capable of living as a saprophyte.

FALLOW—cultivated land allowed to lie idle or unplanted during the growing season.

FASCICLE SHEATH—a sheath around the base of a cluster or bundle of needles.

FEEDER ROOT—succulent actively growing rootlets of plants.

FLAGELLUM(LA)—a whiplike part of some cells, especially of certain bacteria that is an organ of locomotion.

FOLIAGE—leaves of a plant or tree.

WHIP LEAVES—juniper foliage characteristic of long shoot growth on the ends of secondary and tertiary branches.

SPUR LEAVES—juniper foliage characteristic of short (spur) branches.

JUVENILE LEAVES—juniper foliage characteristic of seedlings.

FRUITING BODY—any of a number of kinds of reproductive structures which produces spores. See conk.

FUNGICIDE—chemical which is toxic to fungi.

PROTECTANT—fungicides applied to foliage of plant in advance of a pathogen in order to prevent infection.

ERADICANT—fungicides, applied to foliage of a plant, that have a direct effect upon organisms which have already invaded the host.

SYSTEMIC—fungicides that are absorbed into the tissues of plants and are toxic to fungi.

FUNGUS—any of a number of organisms considered by some authorities to be lower plants which lack chlorophyll.

GALL(BURLS)—pronounced swellings on woody plants caused by certain insects and disease organisms.

GIRDLED—to destroy or remove the tissue, particularly living tissue in a rough ring around a stem, branch, or root.

GUMMOSIS—the giving off of gummy substances as a result of cell degeneration.

HAUSTORIUM(IA)—absorbing organ originating on a hypha of a parasite and penetrating into a cell of the host.

HOST—the plant on or in which a pathogen exists.

HOST RANGE—all hosts which a particular pathogen attacks.

HOST SPECIFIC—a term used to describe those pathogens which attack only certain species of hosts.

HYALINE—transparent, having no color.

HYMENIUM—the general region of the sporocarp bearing the basidia, that is, the layer of tubes. The actual spore-producing layer, made up of basidia and whatever type of sterile organ that may be present with them and forming a layer lining the inside of the tubes.

IMPERFECT STAGE—that part of the life cycle of a fungus in which only conidia and no sexual spores are produced. Syn. asexual.

INFECT—to invade and cause a disease.

INFECTION COURT—the area in which the pathogen first established itself on or in the host.

INFEST—to be present within an area in such numbers as to be a disease hazard.

INOCULATE—to place a pathogen on or in a host in a position in which it is capable of causing a disease.

INOCULUM—the spores, mycelium, sclerotia, or other propogules of a pathogen which initially infect a host or crop.

INTERNODE—the portion of the stem between two nodes.

LATENT INFECTION—an established infection which does not show its presence.

LEAF ABSCISSION—the normal separation of leaves from plants by the development of a thin layer of pithy cells at the base of their petioles.

LEAF PETIOLE—the slender, usually cylindrical portion of a leaf, which supports the blade and is attached to the stem.

LEAF SPOT—a leaf disease characterized by numerous distinct lesions.

LESION—a defined necrotic area.

LIFE CYCLE—the stage or series of stages in fungi between one spore form and the development of the same spore again.

MACROCONIDIA—the larger of two types of conidia by certain fungi, such as *Fusarium* spp.

MICROCONIDIA—the smaller of two types of conidia produced by certain fungi.

MUSHROOM—any of various rapid-growing, fleshy fungi that typically have a stalk capped with an umbrellalike top.

MYCELIUM(IA)—a mass of hyphae which forms the vegetative filamentous body of a fungus.

MYCOPLASMA—a type of disease-causing organism similar to a bacterium, but lacking a true cell wall.

MYCOPLASMA LIKE ORGANISM (MLO)—an organism with apparent features of mycoplasma, but not proven to be mycoplasma.

NECROSIS—death of plant cells usually resulting in darkening of the tissue.

NEMATODE—a roundworm with a long, cylindrical, unsegmented body.

PARASITE—an organism living on and nourished by another living organism.

PATHOGEN—an organism which causes a disease.

PATHOGENIC—capable of causing a disease.

PEDUNCLE—the supporting axis of a single flower or a flower cluster.

PERFECT STAGE—the stage in which the sexual spore stage is produced.

PERENNIAL—continuing growth from year to year.

PERIDERM—the outer protective layer in older stems, consisting of the phellogen and its derivative tissues, phellem and phelloderm.

PERITHECIUM(IA)—a closed flasklike sexual fruiting body formed by certain Ascomycetes in which ascospores are produced.

PERITRICHOUS—having flagella evenly distributed over the entire surface of the cell of a bacterium.

[illegible] tripetally by the phello [illegible]

PHELLOGEN—a lateral meristem that cuts off phelloderm and phellem; the cork cambium.

PHELLUM—the suberized tissue produced by the cork cambium in the bark.

PHLOEM—the tissue of the inner bark responsible for the transport of elaborate food stuffs.

PILEUS(EI)—the upper surface of a sporocarp.

PLEOMORPHIC—the condition in which a fungus has two or more very different morphological forms.

PORE SURFACE—the lower surface of the sporocarp in specimens mature enough to have a tube layer. It is the surface at which the pores open.

PRIMARY INFECTION—infection of a host by primary inoculum, for example, from overwintering spores.

PROLIFERATE—to grow by budding in quick succession.

PRUNE—to remove dead or living parts from a plant to improve its form.

PUSTULE—a small, sometimes colored, blister-like swelling.

PYCNIDIOSPORE—an asexual spore or conidium produced within a pycnidium.

PYCNIDIUM(IA)—an asexual type of fruiting body, typically flask shaped, in which asexual spores or conidia are produced.

PYCNIOSPORE—a specialized spore produced in a pycnium by the rust fungi.

PYCNIUM(IA)—a designation for the spermogonium of the rust fungi.

PYRIFORM—pear-shaped.

RELATIVE HUMIDITY—the amount of moisture in the air as compared with the maximum amount that the air contains at the same temperature, expressed as a percentage.

RESISTANT—able to withstand without serious injury, attack by an organism, or damage by a nonliving agency but not immune from such attacks.

RESUPINATE SPOROCARP—a sporocarp in which the entire structure lies flat on the substratum, i.e. without forming a bracket-like or shelflike body.

RHIZOMORPH—a thick strand of vegetative hyphae in which the hyphae have lost their individuality.

RHIZOSPHERE—the soil near a living root.

ROT—see decay.

SAPROPHYTE—an organism using dead organic material as food.

SAPWOOD—the soft wood just beneath the bark of a tree.

SCLEROTIUM(IA)—a firm, frequently rounded multicellular resting structure produced by fungi.

SECONDARY INFECTION—when a host becomes diseased, the organism commonly produces another crop of spores or infective bodies which serve to cause secondary infection.

SEPTATE—having cross walls which divide hyphae or spores into a number of separate cells.

SEPTUM—the cross wall which divides a hypha or spore into two or more distinct [illegible]

SETA(AE)—conspicuous, conical or lance-shaped, brown, sterile organs found in the hymenium of some fungal species.

SESSILE SPOROCARP—a sporocarp which takes the form of a knob or bracket or shelf. The sporocarp has no stem or stalk, and the point of attachment to the substratum is typically lateral.

SEXUAL STAGE—the stage in the life cycle of a fungus in which spores are produced after sexual fusion. Syn; perfect stage.

SHEARING—cutting foliage and stem from trees with shears.

SHELTERBELT—see windbreak.

SIGNS OF A PATHOGEN—any observable part of a pathogen.

SILVICULTURE—the art of establishing, growing, and regenerating a forest.

SPERMATIUM(IA)—a non-motile, uninucleate, spore-like male structure which empties its contents into a receptive female structure during plasmogamy.

SPERMOGONIUM(IA)—a structure which contains minute, rod-shaped, or oval spore-like bodies which in some cases have proved to be functional spermatia.

SPIROPLASM—a spiral shaped bacterium without a cell wall. Spiroplasms are related to mycoplasmas.

SPORE-the reproductive structure of the fungi and other lower plants.

SPORE HORNS—a tendril-like mass of forced-out spores.

SPORODOCHIUM(IA)—a cushion-shaped stroma covered with conidiophores. Also called a cirrus.

SPORULATE—to produce and release spores.

STOOL BEDS—nursery beds containing plants from which cuttings are obtained during the dormant season for vegetative propagation.

STOMA(MATA)—a pore in the leaf epidermis, surrounded by two guard cells, leading into an intercellular space within the plant.

STROMA(MATA)—a mass of fungal hyphae packed together to form a hard crust in or on which fruiting bodies are formed.

SUSCEPTIBLE—unable to withstand attack by an organism or damage by a nonliving agency without serious injury.

SYMPTOM—the evidence of disturbance in the normal development and function of a host plant, i.e., chlorosis, necrosis, galls, brooms, stunting, etc.

SYSTEMIC—affecting or distributed throughout the whole plant body.

TELIOSPORE—the spore of the rust fungi from which the perfect stage of the basidium and basidispore arise.

TELIUM(IA)—an aggregration of teliospores of the rust fungi.

TENDRIL—a threadlike part of a spore-horn.

TUBE LAYER OF SPOROCARP—a layer of vertically placed tubes attached to the lower surface of the context of a sporocarp. See hymenium.

UREDIOSPORES—one of the many spore stages produced by the rust fungi in their life cycle. These spores are produced in a fruiting body called an uredium.

UREDIUM(IA)—one of the many types of fruiting bodies formed by the rust fungi in their life cycle. Urediospores are formed in this fruiting body.

VECTOR—an organism, usually an insect, that transmits a pathogen from one host to another.

VEGETATIVE MYCELIUM—a mass of hyphae constituting the body of the fungus and without spores.

VIRULENT—vigorously pathogenic.

WETWOOD—a discolored, water-soaked condition of the heartwood of some trees presumably caused by bacterial fermentation. Often associated with distinctive odor, gas production, and an exudation called slime flux.

WHITEROT—decay caused by fungi that attack all chief constituents of wood and leave a whitish or light colored residue. Affected wood is often fibrous or spongy in texture.

WINDBREAK—a row or rows of trees that serve as a protection from wind.

WITCHES'-BROOM—an abnormal cluster of twigs and branches caused by certain pathogens.

XYLEM—the woody conducting tissues of the stem and root.

Index To Host Plants With Scientific Equivalents

Host — **Article Number**

- Ailanthus, *Ailanthus altissima* (Mill.) Swingle 14, 20, 47
- Albizzia, *Albizia* spp. 46
  - Mimosa, *A. julibrissin* Durazz. 46
  - *A. kalkora* (Roxb.) Prain 46
  - *A. lophantha* (Venten) Macbr. 46
  - *A. procera* (Roxb. Benth.) 46
  - *A. pudica* L. 46
  - *A. thorelii* Pierre 46
- Alder, *Alnus* sp. 8, 12
- Almond, flowering, *Prunus triloba* Lindl. 34
- *Amelosorbus* sp. 39
- Apple, *Malus* sp. 14, 15, 34, 35, 39, 48, 49, 62
- Apricot, *Prunus armeniaca* L. 34, 47
- Arborvitae, *Thuja* sp. 50, 52
- Ash, *Fraxinus* sp. 7, 14, 37, 38, 44
  - Black, *F. nigra* Marsh. 6
  - Green, *F. pennsylvanica* Marsh. 6, 7, 14, 37, 38, 47, 49
  - White, *F. americana* L. 6, 27, 37
- Aspen, *Populus* sp. 1, 25, 26, 38
  - Bigtooth, *P. grandidentata* Michx. 26
  - Quaking, *P. tremuloides* Michx. 2, 26
- Autumn-olive, *Elaeagnus umbellata* Thunb. 18
- Basswood, *Tilia americana* L. 7, 12, 14, 31
- Beech, *Fagus* sp. 12, 31
- Birch, *Betula* sp. 12, 14, 15, 37, 38
  - Paper, *B. papyrifera* Marsh. 48
- Buckthorn, European, *Rhamnus cathartica* L. 38
- Buffaloberry, *Shepherdia* sp. 13, 37
  - Russet, *S. canadensis* (L.) Nutt. 13
  - Silver, *S. argentea* (Pursh.) Nutt. 13, 37
- Caragana, *Caragana arborescens* Lam. 3, 4
- Catalpa, Northern, *Catalpa speciosa* Warden 14, 44, 47, 49
- Cherry, *Prunus* sp. 8, 9, 10, 14, 30, 32
  - Carolina cherry-laurel, *P. caroliniana* Ait. 30
  - Cherry-laurel, *P. laurocerasus* L. 34
  - Chokecherry, *P. virginiana* L. 9, 10, 32, 34
  - Hollyleaf cherry, *P. ilicifolia* (Nutt.) D. Dietr. 30
  - Nanking cherry, *P. tomentosa* Thunb. 9
  - Sour cherry, *P. cerasus* L. 10
  - Western sandcherry, *P. besseyi* Bailey 34
- Chestnut, *Castanea* sp. 12, 45
  - American, *C. dentata* (Marsh.) Borkh. 45
  - Chinese, *C. mollissima* Bl. 45
  - Spanish, *C. sativa* Mill. 45
- Chinkapin, *Castanopsis* sp. 45
  - Allegheny, *Castanea pumila* Miller 45
  - Bush, *C. sempervirens* (Kell.) Dudley 45
  - Golden, *C. chrysophylla* (Dougl.) A. DC. 12
- Chokeberry, *Aronia* sp. 10, 39
- Christmasberry, *Photinia* sp. 39
- Cotoneaster, *Cotoneaster* sp. 35
  - Peking, *C. acutinfolia* L. 48
- Corktree, Amur, *Phellodendron amurense* Rupr. 14
- Crabapple, *Malus* sp. 35, 62
- *Crataegomesphilus* sp. 39
- Cypress, *Cuppressus* sp. 30, 50, 53
- Desertwillow, *Chilopsis linearis* (Cav.) Sweet 47
- Dogwood, flowering, *Cornus florida* L. 20
- Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco 56, 60
- Elm, *Ulmus* sp. 7, 8, 12, 14, 15, 16, 29, 41, 42, 43, 44
  - American, *U. americana* L. 16, 27, 29, 41, 42, 43, 49
  - cedar, *U. crassifolia* Nutt. 41, 42, 43
  - Chinese, *U. parvifolia* Jacq. 41
  - English, *U. procera* Salisb. 16
  - Evergreen, *U. parvifolia* Jacq. 41
  - Japanese, *U. japonica* (Rehd.) Sarg. 41
  - Red, *U. rubra* Muhl. 41, 42, 43
  - Rock, *U. thomasii* Sarg. 41
  - *U. rubra* x *U. pumila* hybrid 43
  - September, *U. serotina* Sarg. 41, 43
  - Siberian, *U. pumila* L. 14, 16, 17, 29, 41, 42, 43, 47
  - Slippery, *U. rubra* Muhl. 41, 42, 43
  - Smooth leaved, *U. carpinofolia* Ruppins ex. Suckow 16
  - *U. villosa* Brandis 41
  - Winged, *U. alata* Michx. 41, 43
  - White, *U. americana* L. 16, 27, 29, 41, 42, 43, 49
- Elm zelkova, *Zelkova carpinifolia* (Pall.) C. Koch. 41
- Fir, *Abies* sp. 14
- Flowering-quince, *Chaenomeles* spp. 34, 39
- Gooseberry, *Ribes* sp. 38
- Hackberry, *Celtis occidentalis* L. 14, 36, 41, 47
- Hawthorn, *Crataegus* sp. 35, 39, 62
- Hemlock, *Tsuga* (Endl.) Carr. 59
- Hickory, *Carya* sp. 12, 14, 20, 27
  - Mockernut, *C. tomentosa* Nutt. 27
  - Pecan, *C. illinoensis* (Wangenh.) K. Koch. 30
  - Shagbark, *C. ovata* (Mill.) K. Koch. 27

- [illegible] 12
  - [illegible] 20
- Honeylocust, *Gleditsia tria*[illegible] 12, 14, 27, 37, 46, 49
  - Native thorny, *G. triancanthos* var. *triancanthos* 27
  - Oriental, *G. japonica* Miq. 27
  - Thorny and podless, *G. triancanthos* var. *inermis* Willd. 27
- Honeysuckle, *Lonicera* sp. 11
  - Amur, *L. maackii* Maxim. 11
  - Tatarian, *L. tatarica* L. 11, 48
- Hophornbeam, *Ostrya* sp. 12
- Hornbeam, *Carpinus* sp. 12
- Horsechestnut, *Aesculus hippocastanum* L. 14
- Incense cedar, *Libocedrus decurrens* Torr. 30
- Juneberry, *Amelanchier* sp. 62
- Juniper, *Juniperus* sp. 15, 30, 39, 49, 51, 62
  - African, *J. procera* Hochst. ex. Endl. 62
  - Alligator, *J. deppeana* Steud. 52, 61
  - Ashe, *J. ashei* Buchholz 62
  - California, *J. california* Carr. 62
  - Canary Islands, *J. cedrus* Webb. & Birth. 62
  - Chinese, *J. chinensis* L. 52, 62
  - Common, *J. communis* L. 52
  - Creeping, *J. horizontalis* Moench 52, 62
  - Eastern redcedar, *J. virginiana* L. 30, 47, 50, 51, 52, 61, 62, 64
  - One-seeded, *J. monosperma* (Engelm.) Sarg. 51, 61
  - Rocky mountain, *J. scopulorum* Sarg. 47, 50, 51, 52, 62
  - Savin, *J. sabina* L. 52, 62
  - Singleseed, *J. squamata* D. Don 52
  - Utah, *J. osteosperma* (Torr.) Little 61
- Larch, *Larix* sp. 1
- Lilac, *Syringa* spp. 12, 38
- Linden, *Tilia* sp. 14
- Locust, *Robinia* sp. 38, 46, 49
  (Black, *R. pseudoacacia* L.)
- London plane-tree (an interspecific hybrid) 7
- Maple, *Acer* sp. 3, 4, 7, 8, 12, 14, 15, 31, 37, 38, 44
  - Amur, *A. ginnala* Maxim. 14
  - Bigleaf, *A. macrophyllum* Pursh. 5
  - Boxelder, *A. negundo* L. 14, 37, 48
  - Mountain, *A. spicatum* Lam. 4
  - Norway, *A. platanoides* L. 5
  - Red, *A. rubrum* L. 4, 5
  - Silver, *A. saccharinum* L. 4, 5, 14, 15
  - Soft, *A. saccharinum* L. 4, 5, 14, 15
  - Sugar, *A. saccharum* Marsh. 4, 5, 14, 44
  - Sycamore, *A. pseudoplatanus* L. 5
- Mountain-ash, *Sorbus* sp. 35, 39
- Mulberry, *Morus* sp. 14, 29
  - Russian, *M. alba* f. *tartarica* Seringe 47
- ak, *Quercus* sp. 7, 8, 12, 14, 15, 18, 20, 31, 37, 38, 45, 48
  - Black, *Q. velutina* Lam. 31, 45
  - Bur, *Q. macrocarpa* Michx. 8, 27, 45
  - Live, *Q. virginiana* Mill. 18
  - Northern red, *Q. rubra* L. 31, 45
  - Pin, *Q. palustris* Muenchh. 8, 14, 15, 45
  - Post, *Q. stellata* Wangenh. 45, 49
  - Scarlet, *Q. coccinea* Muenchh. 31, 45
  - Southern red, *Q.* [illegible] 31
  - White, *Q. alba* L. 7, 31, 40, 45
- sage-orange, *Maclura pomifera* (R.F.) Schneid. 47
- each, *Prunus persica* Batsch 8, 10, 15, 62
- ear, *Pyrus* sp. 34, 35, 39
  - Callery, *P. calleryana* Decne. 35
  - Common, *P. communis* L. 35
- Persimmon, Common, *Diospyros virginiana* L. 20
- Pine, *Pinus* sp. 14, 15, 49, 58, 59
  - Austrian, *P. nigra* Arnold 47, 54, 55, 58, 63, 64
  - Bristlecone, *P. aristata* Engelm. 40
  - Eastern white, *P. strobus* L. 63
  - Jack, *P. banksiana* Lamb. 57, 63, 64
  - Japanese black, *P. thunbergiana* Franco 63
  - Loblolly, *P. taeda* L. 63
  - Longleaf, *P. palustris* Mill. 53, 63
  - Lodgepole, *P. contorta* Dougl. 54, 57
  - Monterey, *P. radiata* D. Don 54, 63
  - Mugo, *P. mugo* Turra 57, 58
  - Ponderosa, *P. ponderosa* Dougl. ex Laws. 48, 53, 54, 55, 57, 58, 64
  - Red, *P. resinosa* Ait. 58
  - Scots, *P. sylvestris* L. 6, 48, 53, 55, 58
  - Shortleaf, *P. echinata* Mill. 63
  - Sugar, *P. lambertiana* Dougl. 63
- Plum, *Prunus* sp. 10, 30, 32, 33, 38
  - American, *P. americana* Marsh. 10, 32, 33, 38
  - Cherry, *P. divaricata* Ledeb. 30
  - Chickasaw, *P. angustifolia* Marsh. 33, 38
  - Damson, *P. insititia* L. 32
  - Hortulan, *P. hortulana* Bailey var. *mineri* Bailey 33
  - *Prunus salicina* Lindl. (includes cultivars Formosa, President, Early Italian, Shiro, Santa Rosa) 32
  - *P. domestica* L. (includes cultivars Stanley and Bradshaw) 32
  - Wildgoose, *P. munsonia* Wright & Hedr. 33
- Poison ivy, *Rhus toxicodendron* L. 13
- Poison oak, *Rhus diversiloba* Torr. & Gray 13
- Poplar, *Populus* sp. 1, 3, 14, 15, 21, 22, 23, 25, 29, 30, 37, 38, 49
  - Balsam, *P. balsamifera* L. 22, 24, 25, 26
  - Black, *P. trichocarpa* Torr. & Gray 22, 25
  - Black poplar, *P. nigra* L. 22
  - Cottonwood, *P. deltoides* Bartr. 1, 15, 47
  - Eastern, *P. deltoides* Bartr. 2, 14, 21, 22, 23
  - Gray, *P. canascens* (Ait.) Sm. 31
  - Japanese poplar, *P. maximowiczii* Henry 22
  - Largetooth, *P. grandidentata* Michx. 24, 26
  - Laurel poplar, *P. laurifolia* Ledeb. 22
  - Lombardy, *P. nigra* cv. *italica* Muenchh. 21, 24, 25
  - Mighty-Mo, *P. deltoides* (central Missouri selection) 21
  - Narrowleaf, *P angustifolia* James 2, 25
  - Nor'easter, *P. deltoides* x *P. nigra* cv. *Volga* 21
  - Norway, *P. canadensis eugenci* Hort. Simon-Louis ex. C. Koch 21
  - Plains, *P. deltoides* var. *occidentalis* Rydb. 25
  - Platte, *P. deltoides* (Nebraska selection) 21
  - *Populus* x *canadensis* Muench. cv. *serotina erecta* 30
  - Quaking, *P. tremuloides* Michx. 1, 2, 24, 25, 26
  - Robusta, *P. nigra* x *P. deltoides* 30
  - Siouxland, *P. deltoides* 21
  - Valley, *P. fremontii* var. *wislizenii* S. Wats. 21
  - White, *P. alba* L. 21
- Pyracantha, *Pyracantha* sp. 35
- Quince, *Cydonia* sp. 35, 39
  - Common, *C. oblonga* Mill. 39
- Redbud, *Cercis canadensis* L. 14, 46
- Redwood, *Sequoia semepervirens* (D. Don) Endl. 40
- Rose, *Rosa* sp. 48, 62
  - Multiflora, *R. multiflora* Thunb. 49
- Russian-olive, *Elaeagnus angustifolia* L. 17, 18, 19, 44, 47

Serviceberry, *Amelanchier* spp. 39, 62
Siberian peashrub, *Caragana arborescens* Lam. 3, 4, 38, 49
Skunkbush sumac, *Rhus trilobata* Nutt. 13
Soapberry, western, *Sapindus drummondii* Hook. & Arn. 47
Spruce, *Picea* sp. 14, 49, 59
  Blackhills, *P. glauca* var. *densata* Bailey 56, 60
  Colorado blue, *P. pungens* Engelm. 14, 56, 59, 60, 64
  Engelmann, *P. engelmannii* (Parry) Engelm. 56, 63
  Norway, *P. abies* (L.) Karst. 59, 60
  White, *P. glauca* (Moench) Voss 56, 60, 64
Sumac, *Rhus* sp. 13
  Skunkbush, *R. trilobata* Nutt. 13
Sycamore, *Platanus* sp. 7, 12, 14, 18, 31
  American, *P. occidentalis* L. 7, 14, 18, 20, 31, 47
Tamarisk, French, *Tamarix pentandra* Pall. 47
Tanbark-oak, *Lithocarpus densiflorus* (Hook. & Arn.) Rehd. 45
Walnut, *Juglans* sp. 7, 12, 14, 15, 20
  Eastern black, *J. nigra* L. 7, 19, 38, 47, 49
White-cedar, *Chamaecyparis* sp. 50, 52
Willow, *Salix* sp. 1, 14, 21, 27, 28, 30, 38
  Bebb, *S. bebbiana* Sarg. 38
  Black, *S. nigra* Marsh. 21
  Diamond, *S. rigida* Muhl. 38
  Golden, *S. alba* var. *vitellina* (L.) J. Stokes 38, 49
  Missouri River, *S. eriocephala* Michx. 38
  Peach leaf, *S. amygdaloides* Anderss. 21
  Weeping, *S. babylonica* L. 21
  White, *S. alba* L. 38
Yew, *Taxus* sp. 15

Index To Plant Diseases And Pathogens

Disease Or Pathogen **Article Number**

Acinetobacter sp. (Brison & Prévot) 29
Agrobacterium radiobacter (Beijerinck & Van Delden) Conn 30
Agrobacterium sp. Conn 29
Agrobacterium tumefaciens (Smith & Townsend) Conn 30, 62
Air pollutant damage 14
Anthracnose diseases 7
Antrodia juniperina (Murr.) Niem. & Ryv. 61
Apiosporina morbosa (Schw.) Arx (Syn. *Dibotryon morbosum* (Schw.) Th. & Syd.) 32
Armillaria root rot 45, 48
Bacillus sp. 29
Black knot 32
Black leaf spot 7
Blossom blight 34
Botryodiplodia canker 16, 19, 20
Botryodiplodia disease 18
Botryodiplodia hypodermia (Sacc.) Petr. & Syd. 16, 17
Botryodiplodia theobromae Pat. 17, 18, 19, 20
Botryosphaeria rhodina (Berk. and Curt.) v. Arx 20
Brown rot canker 34, 61
Brown rot fungi 37
Brown spot needle blight 53
Bursaphelenchus xylophilus (Steiner & Buhrer) Nickle 63
Cedar apple rust 39, 62
Cephalosporium wilt 42
Cerambycids 63
Ceratocystis fagacearum (Bretz) Hunt 45
Ceratocystis ulmi (Buism.) C. Moreau (Syn. *Ophiostoma ulmi* (Buism.) 41
Cercospora blight 51
Cercospora sp. Fr. 51
  C. sequoiae Ell. & Ev. 51
  C. sequoiae var. *juniperi* Ell. & Ev. 51
Cherry leaf spot 9
Chlorosis 15
Coccomyces hiemalis Higgins 9
Coccomyces lutescens Higgins 9
Collar blight 35
Contact herbicides 14
Crown gall 30
Cryptodiaporthe populea (Sacc.) Butin 24
Cryptosphaeria canker 25
Cryptosphaeria populina (Pers.) Sacc. 25
Cyclaneusma minus (Butin) DiCosmo, Peredot & Minter 55
Cylindrosporium leaf spot 13
Cylindrosporium shepherdiae Sacc. 13
Cylindrosporium sp. Unger 9
Cylindrosporium toxicodendri Curt. ex Ell. & Ev. 13
Cytospora canker 21, 60
Cytospora chrysosperma Pers. ex Fr. 21, 25
Cytospora kunzei Sacc. 60
Cytospora sp. Ehrenberg 3, 21, 23, 42
Daedalia ambigua Berk. (*Daedalea elegans* Spreng.:Fr.) 28
Daedalia confragosa Bolt. (*Daedaleopsis confragosa* (Bolt.:Fr.) Schroet.) 28
Daedalia stem decay 28, 61
Daedalia unicolor Bull. (*Cerrena unicolor* (Bull.:Fr.) Murr.) 28
Datronia scutellata (Syn. *Fomes scutellatus* (Schw.) Cooke) 37
Diaporthe eres Nits. 23
Diaporthe medusaea N.T. 23
Diaporthe santonensis Sacc. 23
Dibotryon morbosum (Schw.) Th. & Syd. 32
Diplodia blight 58
Diplodia natalensis P. Evans 20
Diplodia pinea (Desm.) Kickx (*Sphaeropsis sapinea* (Fr.) Dyke & Sutton) 58, 63
Diplodia theobromae (Pat.) Now. 20
Dothichiza canker 24
Dothichiza populea Sacc. & Br. 24
Dothiorella wilt 42
Dothiorella ulmi Verrall & May 42
Dothistroma blight 54
Dothistroma pini Hulbary 54
Dutch elm disease 7, 41
Elm dieback 42
Elm yellows 41, 43
Endocronartium harknessii (J.P. Moore) Y. Hirats. 57
Enterobacter cloacae (Jordan) Hormaeche & Edwards 29
(=*Erwinia nimipressuralis* Carter)
Environmental stress 40
Erwinia amylovora (Burrill) Winslow et al. 35
Erwinia nimipressuralis Carter (See *E. cloacae)* 29
Fire blight (See *E. amylovora)* 35
Fomes fomentarius (L. ex Fr.) Kickx 37
Fomitopsis cajanderi (Karst.) Kolt. & Pouz. (Syn. *Fomes subroseus* (Weir) Overh.) 37
Fomitopsis melliae (Underw.) Gilb. (Syn. *Fomes melliae* (Underw.) Murr.) 35
Fruit blight 35
Fusarium sp. Link 3, 23
  Fusarium oxysporum f. sp. *perniciosum* (Hept.) Toole 46
Ganoderma applanatum (Pers.:Wallr.) Pat. (Syn. *Fomes applanatus* (Per. ex Wallr.)) 37

[illegible] 37
[illegible] 7
[illegible] 7
[illegible] spot and anthracnose 7
Gnomonia leaf spot 7
Gnomonia leptostyla (Fr.) Ces. & deNot. 7
Gnomonia platani Kleb 7
Gnomonia quercina Kleb. 7
Gnomonia tiliae Kleb. 7
Gnomonia ulmea (Schw.) Thum 7
Guignardia sp. Viala & Ravaz 4
Gymnosporangium rusts 62, 63
Gymnosporangium sp. Hedwig 62, 63
  G. bethelii Kern. 62
  G. clavariforme (Jacq.) D.C. 62
  G. clavipes C. & P. 39, 62
  G. connersii 62
  G. corniculans Kern. 62
  G. exiguum Kern. 62
  G. globosum Farl. 39, 62
  G. gracile Pat. 62
  G. juniperi-virginianae Schw. 39, 62
  G. nelsonii Arth. 62
  G. nidus-avis Thaxt. 62
  G. trachysorum Kern. 62
Gyrostroma austro-americanum Seeler 27
Heart rot - Daedalea and Trametes 28
Helicotylenchus spp. Steiner (Golden) 49
Herbicide damage 14
Herpobasidium deformans Gould 11
Honeysuckle leaf blight 11
Hoplolaimus sp. Cobb 49
Hormonal herbicides 14
Hypoxylon atropunctatum (Schw. ex Fr.) Cke. 31
Hypoxylon canker 26, 31
Hypoxylon mammatum (Wahl.) Miller 26
Insolibasidium deformans 11
Kabatina juniperi Schneider & v. Arx 52
Kabatina thujae Schneider & v. Arx 52
Kabatina thujae var. juniperi (Schneider & v. Arx) Morelet 52
Kabatina tip blight 51, 52
Lasiodiplodia theobromae (Pat.) Griffon & Maubl. 20
Leaf blisters 8
Leaf rust 1
Leaf scorch 14, 15
Leaf spots 9
Leucocytospora kunzei Hohnel 60
Leucostoma kunzei (Nitschke) Hohnel 60
Libertella sp. Desm. 25
Maple tar spot 5
Marssonina leaf blotch 24
Marssonina leaf spot 2
Marssonina sp. 2, 24
  M. brunnea (Ell. & Ev.) Sacc. 2
  M. fraxini Ell. & Davis 6
  M. populi (Lib.) Magn. 2
MCPA herbicide damage 14
Melampsora medusae Thuem. 1
Melampsora rust 24
Melampsora sp. Castaigne 24
Melasmia acerina Lev. 5
Meloidogyne spp. Goeldi 49
Microsphaera alni D.C. ex Wint. 12
Mimosa wilt 46
Monilinia fructicola (Wint.) Honey 34
Mycoplasma 10
Mycoplasma-like organisms (MLO) 36, 43
Mycosphaerella effigurata (Schw.) House 6
Mycosphaerella fraxinicola (Schw.) House 6
Mycosphaerella leaf spot 6
Mycosphaerella populorum Thompson 3, 22
Naemacyclus minor Butin 55
Naemacyclus needle cast 55
[illegible] elm wilt 42
Nectria cinnabarina Tode ex Fr. 17, 27, 40
Nematodes 49, 63
  Dagger, Xiphinema americanum Cobb 49
  Lance, Hoplolaimus sp. Cobb 49
  Root-knot, Meloidogyne spp. Goeldi 49
  Root-lesion, Pratylenchus spp. Filipjev 49
  Spiral, Helicotylenchus spp. Steiner (Golden) 49
Non-hormonal type herbicides 14
Oakleaf blister 8
Oak wilt 45
Oxyporus populinus (Schum.: Fr.) Donk
  (Syn. Fomes connatus (Weinm.) Gill.) 37
Paraquat 14
Peach leaf curl 8
Perenniporia fraxinophila
  (Syn. Fomes fraxinophilus (Peck) Sacc.) 37
Perenniporia ellisiana (Syn. Fomes ellisianus Anderson) 37
Perenniporia ohiense (Syn. Fomes ohiensis (Berk.) Murr.) 37
Peridermium harknessii J.P. Moore 57
Phellinus conchatus (Pers. ex Fr.) Quél. 38
Phellinus everhartii (Ell. & Gall.) Ames 38
Phellinus gilvus (Schw.) Pat. 38
Phellinus igniarius (L ex Fr.) Quél. 38
Phellinus punctatus (Fr.) Pilát 38
Phellinus ribis (Schum. ex Fr.) Quél 38
Phellinus robineae (Murr.) A. Ames
  (Syn. Fomes rimosus (Berk.) Cooke) 38
Phellinus stem decays 38
Phellinus tremulae (Bond.) Bond. & Boriss. 38
Phellinus tuberculosus (Bawmg) Niemala
  (Syn. Phellinus pomaceus (Pers. ex S.F. Gray) Maire) 38
Phellinus weirianus (Bres.) Gilbn. 38
Phenoxy herbicides 14
Phloem necrosis 43
Phoma sp. (Fr.) Desmaziere 42
Phomopsis blight 50, 51
Phomopsis canker 19, 23
Phomopsis arnoldiae Sutton (Syn. Phomopsis elaeagni) 17, 19
Phomopsis elaeagni (Carter & Sacamano) Arnold & Carter 17, 19
Phomopsis juniperovora Hahn 50
Phomopsis macrospora Kobayashi & Chiba 23
Phomopsis sp. Sacc. 3
Phyllosticta fraxini Ell. & Mort. 6
Phyllosticta gallarum Theum. 4
Phyllosticta leaf spot 4
Phyllosticta minima (Berk. & Curt.) Ell. & Ev. 4
Phyllosticta viridis Ell. & Kell. 6
Phymatotrichum root rot 47
Phymatrotrichum omnivorum (Shear) Duggar 47
Piggotia fraxini B. & C. 6
Plum pockets 8, 33
Pine wilt disease 63
Pinewood nematode 63
Poria stem decays 11, 12
Powdery mildew 12
Powdery mildew fungus 11, 12
Pratylenchus sp. Filipjev 49
  P. penetrans (Cobb) Filipjev & Stekhoven 64
Pseudomonas sp. Migula 29
Pseudomonas syringae pv. syringae (Van Hall) Dye 9
Quince rust 39
Red band disease 54
Rhizosphaera kalkhoffii Bub. 56
Rhizosphaera needle cast 56
Rhytisma acerinum Pers. ex Fr. 5
Root-lesion nematodes 64
Rust fungi 62
Scirrhia acicola (Dearn.) Siggers 53
Scirrhia pini Funk & Parker 54
Sclerotina fructicola (Wint.) Rehm. 34
Septoria aceris (Lib.) Berk. & Br. 3
Septoria canker 22
Septoria caraganae (Jacz.) Diel. 3
Septoria leaf disease 23
Septoria leaf spots 3

Septoria musiva Peck 3, 22
Sirococcus shoot blight 52
Sirococcus strobilinus Preuss 59
Slime flux 29
Sphaeropsis sp. Léveillé 42
Sphaerotheca phytophila Kell. & Swing. 36
Stegophora ulmea (Schw.: Fr.) Syd. & Syd. 7
Sycamore anthracnose 7
Taphrina caerulescens (Mont. & Desm.) Tul. 8
Taphrina communis (Sadeb.) Grs. 33
Taphrina pruni (Fckl.) Tul. 33
Tar spot 5
Thyronectria austro-americana (Speg.) Seeler 27
Thyronectria canker 27
Trametes brown rot 30
Trametes hispida Bagl. (*Funalia gallica* (Fr.) Bond. & Sing.) 28
Trametes malicola Berk. & Curt. (*Antrodia malicola* (Berk. & Curt.) Donk) 28
Trametes mollis (Sommert.) Fr. (*Datronia mollis* (Sommert.:Fr.) Donk) 28
Trametes rigida Berk. & Mont. (*Coriolus floccosa* (Jungh.) Ryv.) 28
Trametes sepium Berk. (*Antrodia albida* (Fr.:Fr.) Donk) 28
Trametes stem decay 28
Trametes suaveolens (L.:Fr.) Fr. 28
Trametes trogii Berk. (*Funalia trogii* (Berk.) Bond. & Sing.) 28
Tubercularia canker 17, 19
Tubercularia ulmea Carter 17, 19
Tubercularia vulgaris Tode: Fr. 17, 27, 40
Twig blight 34
Valsa kunzei Fr. 60
Valsa sorida Nits. 21
Valsa spp. 21
Verticillium sp. Nees 44
  V. albo-atrum Reinke & Berth. 44
  V. dalhiae Kleb. 44
Verticillium wilt 42, 44
Viruses 36
Western gall rust 4, 57
Western X-disease 10
Wetwood 29
White-mottled heart rot 30
White rot fungi 37
Witches'-broom 36
Xanthomonas sp. Dowson 29
Xiphinema americanum Cobb 49
2,4-D Herbicide damage 14

Index To Insect Vectors

Insect — **Article Number**

Beetles
  Lesser European elm bark, *Scolytus multistriatus* (Marsham) 41
  Native elm bark, *Hylurgopinus rufipes* Eichh. 41
  Oak bark, *Pseudopityophthorus minutissimum* (Zimm.) 45
  Sap-feeding, Nitidulidae 45
Colladonus geminatus (Van Duzee) 10
Colladonus montanus (Van Duzee) 10
Contarinia sp. 52
Dichomerus sp. 52
Eriophyid mite, *Aceria* sp. 36
Leafhoppers, Cicadellidae 10, 43
Monochamus sp. 63
  Pine sawyer, *M. alternatus* (Hope) 63
    M. carolinensis (Oliv.) 63
    M. mutator (Say) 63
  Obtuse sawyer, *M. obtusus* (Casey) 63
  Whitespotted pine sawyer, *M. scutellatus* (Say) 63
  Southern pine sawyer, *M. titillator* (F.) 63
Plum curculio, *Conotrachelus nenuphar* (Herbst.) 34
Spittlebugs, Cercopidae 43
Stink bug, *Dixippus* sp. 34

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Abstract

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A Multilevel Optimization System for Large-Scale Renewable Resource Planning

John G. Hof and James B. Pickens

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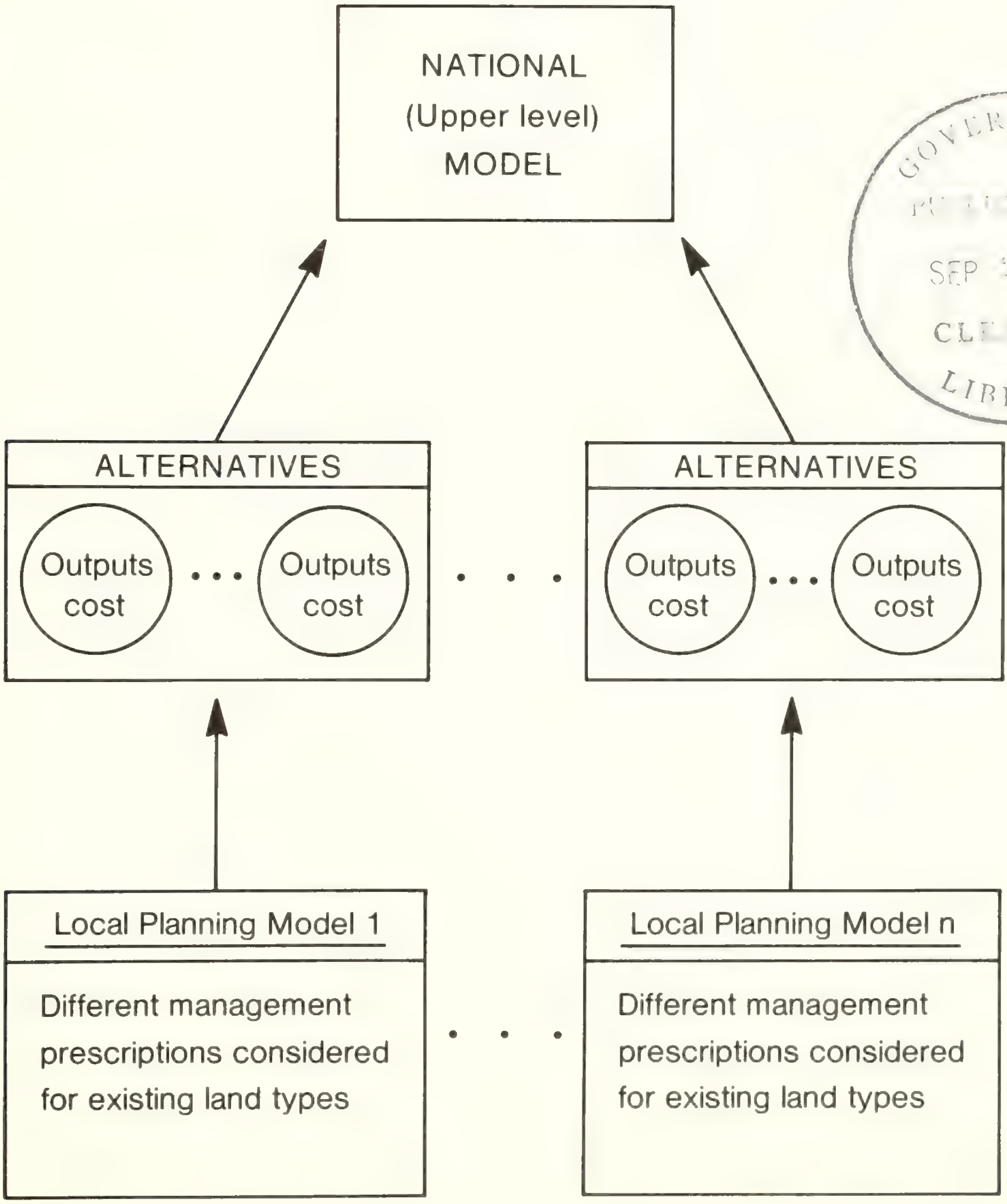

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May 1986

A Multilevel Optimization System for Large-Scale Renewable Resource Planning

John G. Hof, Principal Economist

and

James B. Pickens, Operations Research Analyst
Rocky Mountain Forest and Range Experiment Station[1]

Abstract

This report analyzes and evaluates one approach to utilizing local planning analyses of public renewable resource management agencies as an input in developing large-scale (national) resource management plans. A type of multilevel approach (referred to as the Bartlett-Wong approach) is discussed and is evaluated in a test case. This prototype performed well at the highest level of analysis but was less reliable in terms of its implications for the lower level planning units.

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[1] *Headquarters is in Fort Collins, in cooperation with Colorado State University. James Pickens is now Assistant Professor, School of Forestry and Wood Products, Michigan Technological University, Houghton.*

A Multilevel Optimization System for Large-Scale Renewable Resource Planning

John G. Hof and James B. Pickens

Introduction

Historically, national resource optimization analyses have dealt with very highly aggregated variables and with an extremely low level of resolution. As a result, such analyses could not be validated or monitored. Attempts to disaggregate national planning (optimization) results to local levels also have been generally unsuccessful.

One extreme alternative is to base national planning on simple aggregations of local level optima.[2] However, this alternative is in conflict with the reasons for national planning in the first place: input and/or output constraints (including objectives, etc.) that apply across local planning unit boundaries.

Instead a second alternative—a multilevel approach—is examined here. It utilizes local analyses to generate information for a national analysis that, in turn, can accommodate national concerns and constraints. An example of a use for such an approach is in the development of the USDA Forest Service National (RPA) Assessment and Program.

This report is based on the assumption that the principal purpose of national planning in renewable resource agencies is to select the output mix to be produced and the means of producing it. Although there are many informational outputs of national planning analysis (e.g., price projections, consumption and production projections, resource inventories, and distributional effects on income and employment), this report is limited to efficiency-oriented analysis. It would be impossible to evaluate in one publication all of the different analytical approaches that can be included in national renewable resource planning efforts.

The Problem

For this discussion, define the following variables:

X_1 = budgetary input (cost, ignoring land input)
X_2 = land input
Y_1 = timber output
Y_2 = forage output
f = an implicit production function
Z_i = production factors purchased with budget (X_1)
r_i = factor prices of the Z_i
P_1 = price of timber
P_2 = price of forage.

The "0" superscript is used to indicate a fixed level of the given variable. For this discussion, only two outputs (timber and forage) are considered. It is assumed primary objective of a planning optimization analysis is to locate efficient points—points that are on a production frontier. The optimization problem relevant to public renewable resource planning is somewhat different than the classic economic analysis of production (Silberberg 1978), because one input, land (X_2^o), is not priced and is fixed. The problem is to purchase other inputs (Z_i) with the budget (X_1) so as to produce outputs (Y_j) efficiently. Assuming that there are only two Z's, one way to formulate this problem is

$$\begin{aligned} \text{Minimize: } & X_1 = r_1Z_1 + r_2Z_2 && [1] \\ \text{Subject to: } & Y_1 \geq Y_1^o \\ & Y_2 \geq Y_2^o \\ & X_2 \leq X_2^o \\ & f(Z_1, Z_2, X_2, Y_1, Y_2) = 0. \end{aligned}$$

Solving this problem is essentially attempting to locate an efficient point on a particular production frontier (product transformation curve).

Another way to accomplish basically the same thing is to solve the following problem.

$$\begin{aligned} \text{Maximize: } & P_1Y_1 + P_2Y_2 && [2] \\ \text{Subject to: } & r_1Z_1 + r_2Z_2 \leq X_1^o \\ & X_2 \leq X_2^o \\ & f(Z_1, Z_2, X_2, Y_1, Y_2) = 0. \end{aligned}$$

The P_1 and P_2 simply provide for a given weighted summation of the outputs. Solving this second (revenue maximizing) formulation also amounts to locating points on a production frontier (product transformation curve). If the Y_1^o and Y_2^o in formulation [1] were set at the solution levels for Y_1 and Y_2 in formulation [2], the minimum cost (budget) in formulation [1] would be equal to X_1^o in formulation [2], and the Z_1 and Z_2 in each solution would be the same.

Similarly, a set of cost-efficient alternatives could be generated with formulation [1] by repeated solution with parametric variation in Y_1^o and Y_2^o. Essentially the same thing could be accomplished with formulation [2] by parametrically varying X_1^o, P_1^o, and P_2^o. The two approaches are fundamentally equivalent.

Throughout this report, formulation [2] is generally used for two reasons. First, formulation [1] does not lend itself directly to the traditional formulation of a cost minimization problem, because one input (land) is not costed and is held fixed, which is rather unconventional. Formulation [2], in contrast, holds all inputs fixed, and maximizes some summation of outputs. A solution to formulation [2], therefore, can be interpreted as a point on a production frontier.

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[2] *This means a single aggregation, adding up all of the "preferred" or "final" plans from the local levels. This should be distinguished from an approach where national planning considers a variety of aggregations of different lower level alternatives. Many of the latter sort of aggregations might be possible. For example, if there were 10 different alternative plans for each of 100 local planning units, then there would be 10^{100} different alternative national aggregations.*

Second, formulation [2] allows prespecification of the budget level for the production frontier being analyzed. As will be shown, this is a desirable characteristic for the analysis to follow. Literally, the P_1 and P_2 will be varied to "sample" different points on a given production frontier.

This approach [2] also implicitly maximizes net revenues, because, with a fixed budget, deducting costs from revenues in the objective function is redundant. The scarcity of the inputs is accounted for by the (presumably binding) constraint. For example, to maximize net revenues (or profit)

$$\text{Maximize: } P_1Y_1 + P_2Y_2 - (r_1Z_1 + r_2Z_2)$$

$$\text{Subject to: } f(Y_1, Y_2, Z_1, Z_2, X_2) = 0$$

and, subject to a binding budget and a binding land constraint,

$$r_1Z_1 + r_2Z_2 = X_1^o$$

$$X_2 = X_2^o.$$

This problem can then be rewritten as

$$\text{Maximize: } P_1Y_1 + P_2Y_2 - X_1^o$$

$$\text{Subject to: } f(Y_1, Y_2, X_1^o, X_2^o) = 0.$$

Because X_1^o is a constant $(r_1Z_1 + r_2Z_2 = X_1^o)$, its presence in the objective function does not influence the solution (assuming second order conditions are met) but does influence the shadow prices (on X_1^o and X_2^o). Thus, with a fixed budget, the only motivation for choosing this formulation rather than [2] is whether shadow prices are desired in terms of net revenues or gross revenues. It will be useful here to use formulation [2] so that the budget is fully utilized, even if it implies a solution with less than maximum net revenues. That is, with formulation [2], only the relative magnitude of the output prices to themselves is important; the scale of output prices relative to cost levels is irrelevant. Hereafter, the Z's will be suppressed, and X_1 will be used for simplicity. Note, however, that determination of the vector of inputs (Z_i) purchased with the budget (X_1) is an important part of solving formulation [2]. In the linear programming formulations discussed later, it is principally by varying land allocation and by varying this Z vector that different output vectors are generated. In these linear programs, there are rows to represent budgetary inputs (X_1) and land inputs (X_2), and the Z vector varies across columns that are "management prescriptions" applied to the land.

In national renewable resource planning, an additional problem arises. Whereas the total amount of the land inputs as well as its allocation across local planning units is fixed (by geographic boundaries), even if the total budget input is fixed, the allocation of budget across local planning units is not fixed. And, the allocation of total outputs to local planning units also must be determined (along with total output levels in the first place). Thus, the national problem can be formulated as

$$\text{Maximize: } P_1Y_1 + P_2Y_2$$

$$\text{Subject to: } f_i(X_{1,i}, X_{2,i}, Y_{1,i}, Y_{2,i}) = 0 \;;\quad i=1,n$$

$$\sum_{i=1}^{n} X_{1,i} \leq X_1^o$$

$$X_{2,i} = X_{2,i}^o \;;\; i = 1,n$$

$$\sum_{i-1}^{n} Y_{1,i} = Y_1$$

$$\sum_{i=1}^{n} Y_{2,i} = Y_2$$

or, more simply

$$\text{Maximize: } P_1 (\sum_i Y_{1,i}) + P_2 (\sum_i Y_{2,i})$$

$$\text{Subject to: } f_i(X_{1,i}, X_{2,i}^o, Y_{1,i}, Y_{2,i}) = 0 \;; i=1,n$$

$$\sum_{i=1}^{n} X_{1,i} \leq X_1^o \qquad [3]$$

where the i subscript indicates the i^{th} local planning unit's "share" of the given variable, and n indicates the number of local planning units.

If it were not for constraint [3], that is, if the allocation of budget to local units was predetermined, or if there was no global budget constraint (only local ones), then the global solution would simply be the collection of local solutions. That is, collect, for all i=1,n

$$\text{Maximize: } P_1Y_{1,i} + P_2Y_{2,i}$$

$$\text{Subject to: } f_i (X_{1,i}^o, X_2^o, Y_{1,i}, Y_{2,i}) = 0.$$

To use constraint [3] as the only reason for national planning is to take a very limited view of the reasons for national planning. However, it provides a workable formulation for testing multilevel optimization.

Linear Programming Analysis of Managed Forest Ecosystems

Renewable resource management and planning problems often have been analyzed using mathematical programming techniques such as linear programming (D'Aquino 1974, Ashton et al. 1980). The basic structure of the linear programs commonly used to analyze managed renewable resource ecosystems is depicted in table 1. The simplistic example in table 1 ignores time dimensions and constraints such as budget limitations, even flow restrictions, and minimum output levels. These complexities do not pose analytical problems, but do make the models quite large in some cases. Also, for simplicity, table 1 only includes two outputs: timber and forage.

In table 1, the major column headings are types of land and/or resources. The C_1 through C_5 columns are the number of acres allocated to alternative management prescriptions which could be applied in TYPE 1 (C_1 and C_2) and TYPE II (C_3, C_4, C_5) land. The Timber and Forage rows in the A matrix represent the resource flows per acre that result from implementation of the management prescriptions. For example, $A_{1,1}$ is the output of

Table 1.—A simple depiction of typical linear programs used in renewable resource management and planning.

	Type I		Type II			Outputs		Type	Right-hand side
	C_1	C_2	C_3	C_4	C_5	Timber	Forage		
Timber	$A_{1,1}$	$A_{1,2}$	$A_{1,3}$	$A_{1,4}$	$A_{1,5}$	-1		=	$K_1 = 0$
Forage	$A_{2,1}$	$A_{2,2}$	$A_{2,3}$	$A_{2,4}$	$A_{2,5}$		-1	=	$K_2 = 0$
TYPE I	1	1						=	K_3
TYPE II			1	1	1			=	K_4
Objective function	$-A_{5,1}$	$-A_{5,2}$	$-A_{5,3}$	$-A_{5,4}$	$-A_{5,5}$	$A_{5,6}$	$A_{5,7}$		

timber for each acre on which management prescription C_1 is implemented. The TYPE I and TYPE II rows are the land inputs to this production system. K_3 acres of Type I land are available, and K_4 acres of Type II land are available.

The Outputs (Timber and Forage) are accounting columns that collect the outputs described in the first two rows into aggregate outputs for the area being analyzed. K_1 and K_2 are set at zero to force all product output levels into these columns. The coefficients in row 5, the Objective Function row, describe the change in net revenues if one unit of C_1 occurs. Thus, $A_{5,1}$ is the cost of prescription C_1 on one acre, and $A_{5,6}$ is the revenue derived from one unit of timber output. This row is often the objective function to be maximized. As discussed previously, cost (budget) might also be constrained and revenue might be maximized, or outputs might be constrained and cost might be minimized.

Problems in Applying Linear Programming at the National Level

Planning for optimum management of national renewable resources is a staggering problem because of conflicting needs for detail and scope. Analyzing relatively small areas of land (such as a National Forest) is appealing because of the relative detail, resolution, and accuracy that can be achieved in a model such as that depicted in table 1. However, common inputs or outputs may enter the problem across local boundaries, increasing the desirability of a larger scale analysis that can capture absolute and comparative advantages between local land units. Thus, local level optima cannot simply be added up to yield an optimal national plan. The ideal solution would be the use of a single national analysis that is capable of achieving high levels of resolution and detail. Unfortunately, such a model would be huge and unworkable. For example, typical FORPLAN (Johnson et al. 1980)[3] models used at the national forest level in USDA Forest Service land management planning are large enough to stress the capabilities of modern computer systems. Attempting to agglomerate the FORPLAN models from the 120 forest planning units into one national model would not be possible.

Decomposition Models

One approach to solving certain very large optimization problems is "decomposition" of the problem. As Dantzig and Wolfe (1961) state:

> Many linear programming problems of practical interest have the property that they may be described, in part, as composed of separate linear programming problems tied together by a number of constraints considerably smaller than the total number imposed on the problem.... It would seem that each of the *n* sets of constraints ... constitutes a "subproblem" of secondary importance to the whole program, and that they should be studied mainly through the restrictions they impose on the activities of the "joint" constraints...

Dantzig (1963) noted that,

> The price paid for this decomposition is that the master program and the subprogram may have to be solved several times. First the master program is solved, and from its solution, objective functions are generated for each of the subprograms. Then these are solved, and from their solution new columns are generated to be added to the master program. The process is then repeated until, after a finite number of cycles, an optimality test is passed.

Kornai and Liptak (1965) emphasized the interpretation of decomposition as a multilevel optimization problem. Kornai (1975) later clarified that the real distinction between Dantzig and Wolfe's approach and theirs was that theirs was a "direct" procedure that did not go through the so-called "extremal problem." Kornai (1975) also clarified that both approaches (and a number of other ones) can be considered to be members of the "family of decomposition procedures."

The Kornai and Liptak (1965) approach (for a two-level problem) involves a "game-theoretical model" between a higher level planning authority (the "center") and a set of sectoral planning units. The center makes an initial, provisional distribution of the "available resources, material, manpower, etc. among the sectors, and at the same time also indicates their output targets." The sectors then rigorously analyze this set of "quotas" and report back "one type of economic efficiency index—the shadow prices derived from programming." The center then modifies the resource and output "quotas" based on this information. By iterating back and forth, a sectoral allocation is arrived at that, within a given tolerance level, equates the shadow prices across sectors, and thereby reaches a global optimum.

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[3] *Johnson, K. N., D. B. Jones, and B. M. Kent. 1980. Forest planning model (FORPLAN) user's guide and operations manual. Available from Systems Application Unit, Land Management Planning, USDA Forest Service, Fort Collins, Colo.*

Both the Dantzig-Wolfe (DW) approach and the Kornai-Liptak fictitious play (FP) approach are shown to converge to a solution with continued iterations between sectors and the center. In further comparing the two basic approaches, Kornai (1975) stated:

> ...two main classes may be distinguished. In one of these shadow prices are sent down from above and indicators of the volume type are sent upwards from below. The "ancestor" of this class is the DW algorithm. In the other class, volume type indices are sent down from above and shadow prices are sent upwards from below. The pioneer of this second class was the FP algorithm.

Problems in Applying a Decomposition Model at the National Level

There are two principal problems in applying a DW or FP model to a national renewable resource planning problem. First, it would be quite rare for all of the local planning units (such as national forests) to complete their planning efforts simultaneously. Second, the communications network and coordinating authority to implement the repeated iterations necessary in a DW or FP model generally are not present. An alternative is needed that allows the local planning units to operate more independently and still allows an integration of these efforts without serious suboptimization (in the global sense).

The Bartlett-Wong Approach

Work by a number of researchers, most notably Bartlett (1974) and Wong (1980), suggests that national level analyses could focus on control by the selection of discrete management alternatives provided (perhaps over a period of years) by the lower levels of the organization. This approach has not been developed or tested. This report develops the details of this approach and tests it in a case example.

Figure 1 depicts the basic structure of this analytical approach. The local level linear programs are used to construct discrete management alternatives for consideration at the national level. The national level model would also most logically be a mathematical program. Table 2 depicts the programming matrix of a very simple linear programming version of a national model. In this example, only two local planning units, two alternatives, and two products are included. Also, only one time period is included. Expansion beyond the dimensions of this simple example is relatively straightforward.

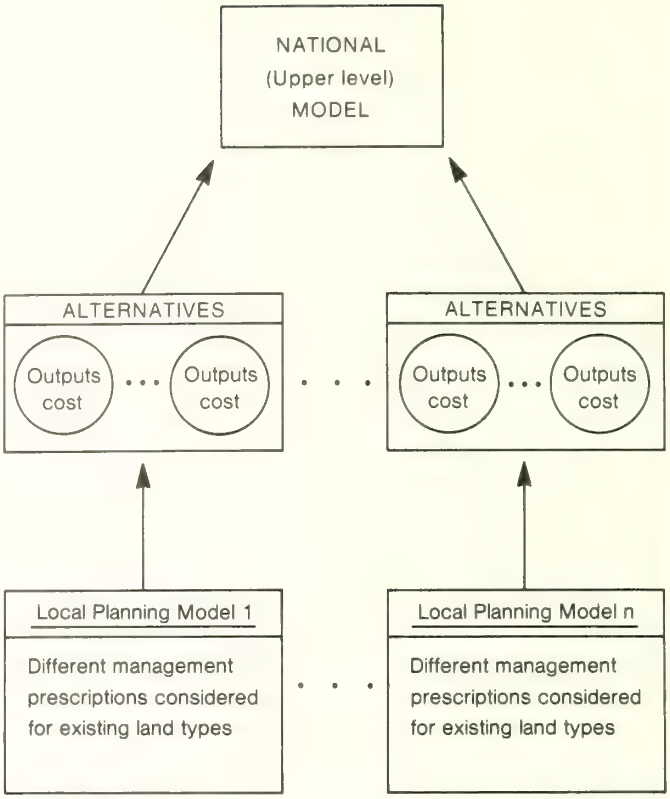

Figure 1.—Multilevel modeling structure for national level planning analysis.

In table 2, X_1^1 through X_2^2 are 0–1 variables representing selection or rejection of an alternative output vector with associated joint cost ($A_{3,i}$; i = 1,4), for a given local planning unit. For example, X_1^1 represents selection (1) or rejection (0) of the output vector $A_{1,1}$ and $A_{2,1}$ in Local Planning Unit 1. The first two rows collect the outputs from selected alternatives, and the fifth row is the objective function to be maximized. In this case, (global) budget is constrained (fourth row) and revenue is maximized. All of the matrix below the objective function row constrains the X_1^1 through X_2^2 so that each of them is between 0 and 1, and so that a "total" of only one alternative can be selected for each local planning unit. Because this is a linear programming model with continuous variables, X_1^1 through X_2^2 may actually take on solution values between 0 and 1 but not equal to either. For example, X_1^1 and X_2^1 in table 2 might solve with values of 0.6 and 0.4, respectively. This is interpreted as a partial selection of each alternative, the combination of which satisfies the "0–1 model constraints." This can be avoided if the national model is solved with an integer program. This option is discussed later.

The principal advantage of this multilevel optimization is that the detail and high resolution of local level analyses are preserved, but national optimization with a global budget constraint is still allowed—the national optimum will not simply be a summation of local optima. The implied national model reflects much detailed production analysis, but is itself of very workable size and complexity. And, any national model solution can automatically be disaggregated to a set of local management

Table 2.—A simple upper level model structure.

	Local planning unit 1		Local planning unit 2		Outputs		Cost	Type	Right-hand side
	X_1^1	X_2^1	X_1^2	X_2^2	Timber	Forage			
Timber	$A_{1,1}$	$A_{1,2}$	$A_{1,3}$	$A_{1,4}$	−1			=	0
Forage	$A_{2,1}$	$A_{2,2}$	$A_{2,3}$	$A_{2,4}$		−1		=	0
Cost	$A_{3,1}$	$A_{3,2}$	$A_{3,3}$	$A_{3,4}$			−1	=	0
Global budget constraint							1	≦	K
Objective function					B_T	B_F			MAX
0-1 Model constraints	1	1						=	1
			1	1				=	1

plans. The main shortcoming of this multilevel optimization approach is that limiting the national analysis to a finite, in fact relatively small, number of discrete choices may overlook desirable options and lead to suboptimization.

The Bartlett-Wong approach might be contrasted with the DW and FP approaches as follows. In the DW and FP approaches, the center (national planners) and the sectors (local planning units) iterate back and forth to converge on a solution that is known to be optimal within some prespecified level of tolerance. In the process of this iteration, the sectors must run their local models several (perhaps many) times, and each run is directed by the center based on the information gained from the previous iteration(s). In the Bartlett-Wong model, however, the center must direct the sectors to perform a full set of runs based only on whatever information is available. These local runs may be performed at different times, as the models are available. The center must try to anticipate a set of sectoral runs that will be needed in searching for a global optimum (or an approximation thereof). The DW and FP approaches were shown (Dantzig and Wolfe 1961, Kornai and Liptak 1965) to always converge to approximate optimal global solutions. Because such a proof is not possible for the Bartlett-Wong approach, a test case is presented here to evaluate its tendency to suboptimize. The Bartlett-Wong approach is considered as a possibility because it currently seems pragmatically more useful than the DW and FP approaches for national renewable resource agencies. In any situation where the more elegant DW or FP type of approach is pragmatically feasible, its use probably would be preferable, because each has been shown to always converge to a given approximation of optimality. The test case evaluation of the Bartlett-Wong model cannot be used to generalize, and should be interpreted accordingly. All inferences and conclusions drawn are based solely on this single experiment.

Alternative Forms of the Bartlett-Wong Approach

Different Ways to Derive Lower Level Alternatives

Figure 2 is a simple production possibilities curve for a given lower level planning unit, one time period, and two outputs. Timber and forage are competitive outputs with one product transformation relationship, described by arc AB. This particular product transformation curve corresponds to an implicit budget level b_1. Larger budgetary expenditures, such as b_2, would shift the transformation curve to the right, as in arc CD. An alternative describes some mix of timber and forage outputs, and is depicted by a point, such as P_1, on one of the tranformation curves. The set of alternatives used to describe this simple production unit's capabilities should approximate the product transformation relationships at various budget levels. For example, alternatives P_1, P_2, and P_3 might approximate these relationships for budget b_1, while P_4, P_5, and P_6 correspond to budget b_2, and so forth.

Given such a production unit, systematic development of alternatives could proceed from at least three different approaches:[4]

1. Set the budget at a particular level, for example b_1, and obtain alternatives (e.g., P_1, P_2, and P_3) by varying the *relative* output prices (i.e., the objective function arguments) and maximizing revenue. This could be done for several budget levels. This would result in a group of alternatives depicted by the P's in Figure 2.
2. Set the output mix (e.g., at A_2) and minimize costs to determine the required budget level. This could be done for a number of output mixes. Production possibility curves could only be approximated if, by chance, alternatives with similar budget requirements obtained. This approach generally would result in a group of alternatives depicted by the A's in Figure 2.
3. Set the absolute output prices at a variety of levels and then maximize net revenue with no budget constraints. Different budget levels and product mixes would result from the different absolute magnitude of the prices. This approach also would generally result in a group of alternatives depicted by the A's in Figure 2.

[4] *In current practice, alternatives often are not developed in a systematic manner (i.e., they are developed with a combination of the three different approaches discussed here). This probably occurs because local planning efforts are directly oriented towards local planning. If local planning efforts are to support a multilevel national planning analysis, then systematic development of alternatives would be especially desirable.*

Approaches 2 and 3 generally will not yield groups of alternatives that can be associated with a particular budget. It would only be chance that more than one alternative would have the same budget level. For the analysis discussed here, it was judged to be very desirable to have alternatives placed into groups with the same budgets.

Briefly, this type of grouping produces a model where successive (each associated with a given budget) production possibilities curves are piecewise approximated. Approaches 2 and 3 yield a scattering of points, each on a different production possibilities curve. Interpolations between alternatives that have the same budget level are viewed differently than interpolations between alternatives that have different budget levels. Only approach 1 allows making this distinction.

Another important consideration is that the global budget will be the constraint that cuts across all local planning units and thus makes the national model necessary. Approach 1 is the only one (including combinations of the approaches) that allows the analyst to ensure a particular level of variation in local budgets across the local alternatives developed. Budgetary variation in the alternatives is critical to the performance of the multilevel model. Using either approaches 2 or 3 might result in only very narrow ranges in local budgets or ridiculously wide ranges in local budgets that leave too much unknown space between them. Also, with approach 3, unless considerable information on costs and output prices is available, meaningless results may be obtained because of absolute prices being set way out of scale with costs. Finally, approach 1 is clearly advantageous in terms of model interpretation.

Approach 1 therefore, will be adopted for the remainder of this discussion. Within this approach, significant questions remain involving the number of alternatives that are desirable and the specific definition of the different alternatives included. These questions are examined in the test case.

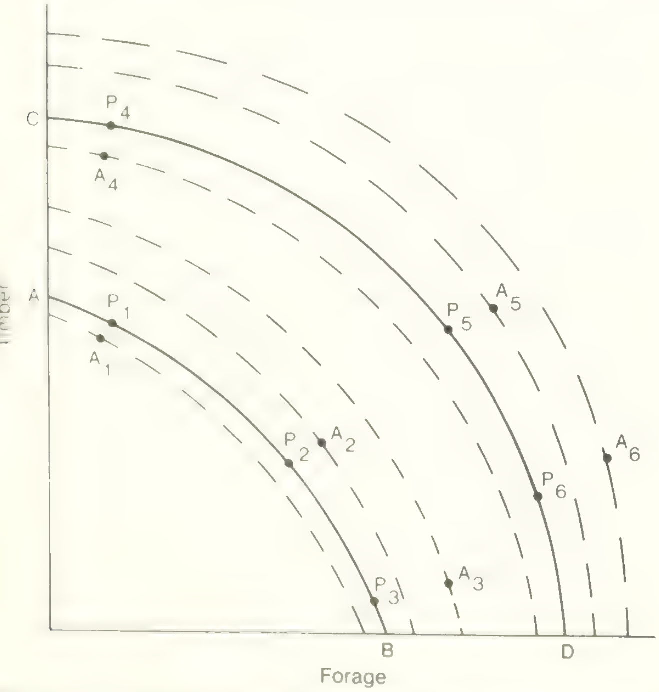

Figure 2.—A two-output, one-time-period, production possibilities curve for a given local planning unit.

Linear Programming Versus Integer Programming Solutions to the Upper Level Model

Referring to table 2, the point was made that if the upper level model is solved with a linear program, X_1 through X_4 may actually take on solution values between 0 and 1. For example, X_1 and X_2 in table 2 might solve with values of 0.6 and 0.4, respectively. Again, this is interpreted as a partial selection of each alternative, the combination of which satisfies the "0–1 model constraints." It is basically a linear interpolation between two alternatives. The interpolated cost would be only an approximation of unknown reliability (investigated below). An alternative approach would be to solve the upper level model in a way such that only complete alternatives can be discretely selected.

Three options should be considered. First is the completely continuous variable linear program as depicted in table 2. Second is the option of treating all alternatives discretely and solving the model with an integer program where all choice variables are constrained to be zero or one. This model would look exactly like that in table 2, except that X_1 through X_4 would be constrained to be integers. The third option would allow interpolations between alternatives that have the same budget, but would not allow interpolations between alternatives that have different budgets. This distinction is important, because interpolations between alternatives with the same budget merely create a piecewise approximation of a given production possibilities curve. An interpolation between alternatives with different budgets involves approximating the rate of expansion of the product transformation curve (with increasing outlay). The first type of interpolation is different from the second from an economic point of view, and the former may be more tenable (safer) than the latter. Table 3 depicts a simple model of this type. It is similar to that in table 2, but includes four alternatives ($X_1 - X_4$) for each local planning unit. It also includes rows that create the "mixed integer" model.

Figure 3 depicts the production possibilities map for a given local planning unit (where a partial selection occurs) with the first option—a continuous variable linear program. All points between any two alternatives are allowed (potentially) in the solution. In contrast, figure 4 depicts a similar production possibilities map that results from the second option—an all-integer program that treats all alternatives as discrete choices. Only the discrete alternatives specified in the upper level model are allowed. The third option is similarly depicted in figure 5. As indicated previously, this is a compromise that allows all points between alternatives with the same budget but does not allow points between alternatives with different budget levels to enter solution.

With only one global (budget) constraint and linear objective functions, the distinction between option two and

Table 3.—A simple mixed integer upper level model structure.[1]

	Local planning unit 1				Local planning unit 2				Integer variables				Outputs		Cost	Type	Right-hand side
	Budgets				Budgets												
	1		2		1		2										
	X^1_1	X^1_2	X^1_3	X^1_4	X^2_1	X^2_2	X^2_3	X^2_4	I^1_1	I^1_2	I^2_1	I^2_2	Timber	Forage			
Timber	t	t	t	t	t	t	t	t					−1			=	0
Forage	f	f	f	f	f	f	f	f						−1		=	0
Cost (Budget)	c	c	c	c	c	c	c	c							−1	=	0
Mixed integer constraints	1	1							−1							=	0
			1	1						−1						=	0
					1	1					−1					=	0
							1	1				−1				=	0
									1	1						=	1
											1	1				=	1
Objective function													B_T	B_F			MAX
Global budget constraint															1	≦	K

[1] *To conserve space, the subscripted A-matrix (as in table 2) is represented here simply with the "t," "f," and "c" entries.*

option three is moot. That is, under these conditions, option three will always result in an all-integer solution — the solution would always be one of the corner points in figure 5. However, using option three may provide for considerable computational savings and improved solvability, relative to option two. Because the tenability and usability of options one and three are not yet clear, they are discussed in the test case also.

Number of Levels

Another issue concerning the configuration of a multilevel optimization model involves the number of levels in the model. In a given institutional setting there may be requirements for a particular number of levels. However, if the objective is to approximate a national optimum, only two levels should be employed.

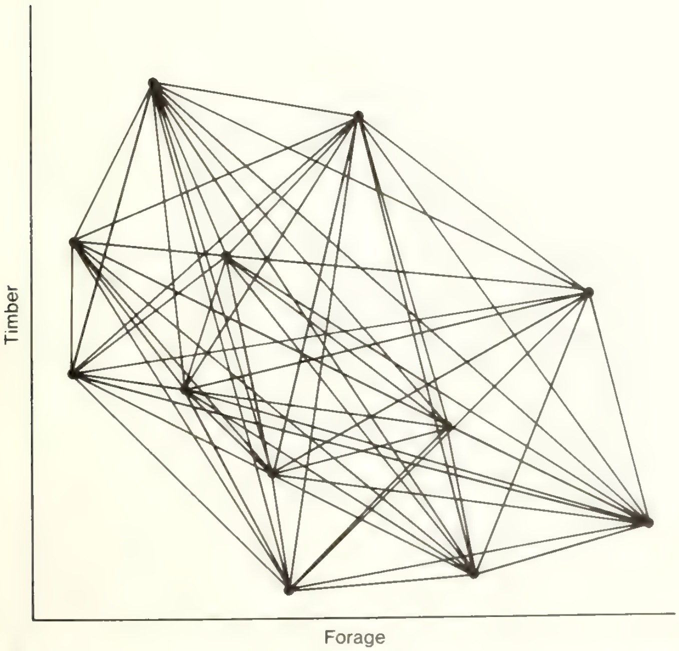

Figure 3.—A graphical depiction of the production space for a given local planning unit in a continuous variable linear program upper level model.

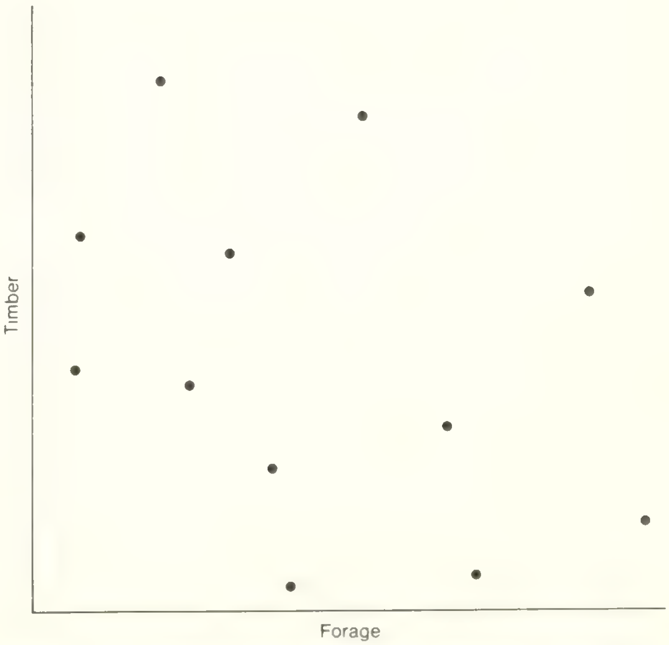

Figure 4.—A graphical depiction of the production space for a given local planning unit in an all-integer program upper level model.

As an example, consider a planning problem with 100 lower level planning units. Assume that there are only 10 discrete alternatives to be considered for each lower level model. With two levels, the higher level model for this problem in the form of table 2 would have 1,000 columns. Next consider the insertion of an intermediate level such that the same problem would be analyzed with three levels. That is, the lowest level would generate alternatives for the intermediate level model, and then the intermediate level model would generate alternatives for the national level model. Both the intermediate level models and the national model would be in the form of table 2. If each intermediate level planning unit is composed of 10 of the lowest level planning units, then each of the intermediate level models would have 100 columns. However, if all of the information (alternatives) in the two-level model is to be retained at the national level of the three-level system, then each intermediate planning unit would have to pass up 10^{10} discrete alternatives to the national model—every combination of lowest level alternatives. The national model would then have 10^{11} columns (10^{10} columns for each of 10 intermediate level planning units). If partial selections are allowed between the discrete alternatives, or if more alternatives per local planning unit are included, then the problem gets substantially worse.

If a particular institutional setting requires more than two levels, this must be weighed against the increased technical difficulties before adopting either approach. Again, it is assumed that the objective is to approximate national optima, not to integrate several levels of planning. The test case demonstrates that intermediate level information can easily be reported (or for that matter constrained) in the two-level approach.

In summary, both linear programming and integer programming versions of the upper level model in a two-level system should be tested for suboptimization and resource misallocation. Also, different numbers and types of local alternatives might be included in the upper level models, and these options should also be tested. These local alternatives will be generated by constraining local cost (budget) to a variety of levels and maximizing revenue with a variety of relative timber and forage output prices.

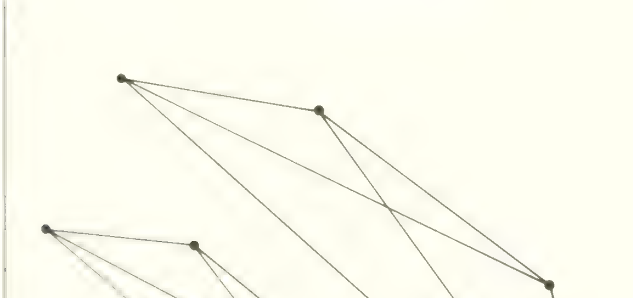

Figure 5.—A graphical depiction of the production space for a given local planning unit in a mixed-integer program upper level model.

A Test Case

The basic approach to the test case was to locate a suitable single-level global model that would serve as a standard for comparison, and then to build multilevel (two-level) models out of the global model. The lower level models in the multilevel system were built simply by subdividing the global model (Appendix 1) geographically. The alternatives for the upper level model(s) were generated by repeatedly optimizing the subdivisions (local planning units) with different local budget constraints and different relative price vectors in the revenue-maximizing objective function. Next, the upper level model(s) were tested for suboptimization with a variety of relative price vectors and global budget constraints. A mathematical description of the models used in the test case is presented in Appendix 2.

The Global Model

The model used for the test case was the National Interregional Multiresource Use Model (NIMRUM) for the land base described here. The NIMRUM model (Ashton et al. 1980) was developed for use by the USDA Forest Service to satisfy the requirements of the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA). A complete description is presented in Appendix 1. Its basic structure is similar to that depicted in table 1. The data were developed using an interdisciplinary team approach. The participants in the interdisciplinary teams were mostly Forest Service employees, together with some other federal agency and state government individuals.

The land base used in developing the test case models included all forest and range lands in USDA Forest Service Regions 4, 5, and 6, which includes all of or major portions of Idaho, Wyoming, Utah, Nevada, California, Oregon, and Washington. This large area was chosen to have a wide variety of production capabilities and ecosystem types. Because the context of the test case is a system for national planning analyses, this was considered to be an important test characteristic.

In all of the multilevel model tests, the local planning units are the same. There are 14 of them consisting of the 7 states divided into National Forest System and non-Forest System lands. This was merely a convenient way to define a reasonable number of local planning units. The analysis is organized simply to emulate a large-scale resource planning problem. No policy implications are intended regarding the actual production or cost results or regarding any apparent comparisons between different lands or ownerships.

Ten Different Upper Level Models

Two terms are defined for the discussion that follows. First, model "type" indicates whether the upper level model is a continuous variable linear program, or an integer program. Second, model "configuration" indicates the number and breadth of the different alternative output vectors included in the upper level model for each local planning unit.

Five different upper level model configurations were constructed, each with a different set of alternatives included for each local planning unit. Each configuration was constructed for the two solution types: continuous variable linear programming and integer programming. This yielded 10 different upper level models. As discussed previously, a mixed integer formulation that always yields an all-integer solution was used for computational efficiency.

Forage and stumpage prices vary significantly across the global model land base (Forest System Regions 4, 5, and 6). The NIMRUM model assumed different prices for each region. This assumption was adopted in this study also. This amounts to defining different timber and forage outputs for each region. In any actual national planning effort, commodities probably would not be homogeneous across the entire nation. Regional pricing provides a simple way of depicting this pragmatic complication. In an actual planning problem, a simple regional commodity definition may not be the best approach. The base prices, based on those used in USDA Forest Service (1980), are as follows.

	Timber $\$/1,000\ ft^3$	Forage $/AUM
Region 4	303	4.96
Region 5	833	6.00
Region 6	1146	5.90

The relative price vectors used in building the multilevel model(s) are all multiples of the base prices, and thus retain the proportional regional price differences.

A pool of alternatives for each local planning unit was developed, from which the different upper level models could be built. First, a "base" run was generated for each local planning unit. These were unfettered (no budget constraint) local maximizations of net value, using the prices described. Based on the costs (budget outlays) for each local planning unit in these base runs, the following four budgets were defined for each local planning unit: (1) 50% of the local base budget; (2) 75% of the base budget; (3) 100% of the base budget; and (4) the local budget required when output prices were doubled and an unfettered net value optimization was run. The last option was included to permit a greater than base level production capability that is not arbitrarily high, but instead is associated with particular price increases.

After the four budget levels were defined for each local planning unit, sets of points on the production possibility frontiers were located by fixing the budget level and maximizing weighted outputs. In this context the weights can be viewed as relative prices. Five different relative price vectors were constructed. Because variation in relative prices is desired, the forage prices were held at their base levels. Each of the relative price vectors was run with each local budget level to generate a pool of 20 alternatives for each of the 14 lower level models.

Five different upper level model configurations were built from this pool of local alternatives, for which the following codes were used.

Local pricing code	Local relative price vectors
1	Stumpage prices at 10 times the base stumpage prices
2	Stumpage prices at 3 times the base stumpage prices
3	Stumpage prices at base stumpage prices
4	Stumpage prices at 1/3 of the base stumpage prices
5	Stumpage prices at 1/10 of the base stumpage prices

Local budget code	Local budget level
1	50% base
2	75% base
3	100% base
4	Twice the base price net value maximization budget

The five different upper level model configurations (labeled 1, 2A, 2B, 3, and 4) included the following alternatives for each local planning unit.

Configuration	Local budgets included	Local prices included	Total number of alternatives for each local planning unit
1	1,2,3,4	1,2,3,4,5	20
2A	1,3,4	1,3,5	9
2B	1,3,4	2,3,4	9
3	1,4	1,5	4
4	1,3,4	3	3

Nine Tests of the Upper Level Models

The global model and each of the 10 upper level models were solved with three different global budget constraints,[5] and three different relative price vectors for each global budget constraint. Comparing these solutions provides the tests for suboptimality in the upper level models. The three global budgets for testing purposes were

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[5] *The term "global budget constraint" applies to a fixed budget level for the entire planning area (all 14 local planning units). This "global budget constraint" is applied to both the "global" model and the "multilevel" or "upper level" models.*

Low: 0.625 times the sum of local base (code 3) budgets
Medium: 0.875 times the sum of local base (code 3) budgets
High: The midpoint between the sum of local base (code 3) budgets and the sum of code 4 local budgets.

The three different relative price vectors used in testing the upper level models were:

Low relative timber prices: 0.2 times the base timber prices
Medium relative timber prices: Base timber prices
High relative timber prices: 5 times the base timber prices.

All timber prices are taken with the base forage prices.

The partial selections that resulted from linear programming solution of the upper level models also were analyzed to determine the accuracy of the interpolated cost implied. All nine tests were performed for both linear programming solutions and integer programming solutions of the five different upper level model configurations. Thus, the global model was solved nine times, and each of the 10 upper level models was solved nine times with budgets and relative prices varied systematically. Comparing these solutions indicates the tendency of the upper level models to suboptimize.

Results and Discussion

Objective Function Test Results for Linear Programming Solution of the Upper Level Models

Table 4 presents a set of ratios between the five different upper level linear program solution objective functions and the same for the global model. This gives a general picture of the suboptimality introduced by the multilevel alternative to global optimization.

For the Model 1 configuration, the upper level model objective function solution value is clearly very close to the global one. The only instance where the suboptimality (as measured here) is more than 1% is in the test using the low budget and high relative timber prices. This test is stressing the multilevel model severely and is still within 4% of the global model. On the basis of these results, if a model configuration as large (20 alternatives per lower level planning unit) as Model 1 can be used, relatively reliable optimality results should be expected. That is, these results indicate minimal suboptimality for Model 1.

Models 2A and 2B (which each have nine alternatives for each lower level planning unit) do not perform much worse. The only instance where the suboptimality is more than about 2% is, again, the test with the low global budget constraint and the high relative timber price. In this instance, the suboptimality is about 5% for each model. Again, minimal suboptimality has occurred, based on these figures.

The fourth column—applying to Model 3—is less encouraging. This model had only four alternatives per local unit, and only two different local budget levels were included for each lower level land unit. This configuration resulted in suboptimization as much as 13.5% and only rarely resulted in suboptimization less than 5%.

In contrast, the last column—applying to Model 4—is more promising. This model had only three alternatives for each lower level land unit, and yet performed better than Model 3. The reason is that Model 4 included three different budget levels for each local planning unit. Because the global budget constraint creates the need for higher level planning and modeling in the first place, it is reasonable that more variation in the budget allocation across lower level land units would be more important than sheer number of lower level alternatives.

Other implications are evidenced by comparing the different columns in table 4. Models 2A and 2B both included nine alternatives for each local planning land unit, and the suboptimality results are essentially the same. Remembering that the only difference between Models 2A and 2B are the price vectors used in developing the local level alternatives, it is apparent again that budget variation across lower level alternatives is more important than price vector variation. This is equivalent to saying that for national optimization (as formulated here),

Table 4.—Ratios of objective function solution values of different upper level linear programming models to those of the global model.

Global budget constraint	Relative timber prices	Upper level linear programming				
		1	2A	2B	3	4
High	High	0.9908	0.9900	0.9869	0.9839	0.9723
High	Medium	.9942	.9942	.9942	.9276	.9942
High	Low	.9931	.9911	.9897	.9683	.9725
Medium	High	.9921	.9891	.9881	.9175	.9556
Medium	Medium	.9977	.9898	.9898	.8650	.9898
Medium	Low	.9963	.9918	.9925	.9498	.9633
Low	High	.9632	.9517	.9461	.9093	.8983
Low	Medium	.9922	.9826	.9826	.8850	.9826
Low	Low	.9960	.9928	.9936	.9063	.9415

it is more important for local level analyses to study the effects of varying budgets than to study alternative output mixes at a given budget. Even in tests with relative timber prices far different (by a factor of 5) than the single price vector used in developing Model 4, it performs reasonably well.

In comparing Models 2A and 3, note that Model 3 is the same as Model 2A, except that in Model 3 the alternatives for each local planning unit with the middle local budget levels and the middle relative price vectors were not included. Thus, Model 3 only includes the "outside" alternatives, leaving out the "middle" ones. This results in Model 3 performing particularly poorly for the medium global budget and the medium relative timber price tests. Because these tests are the least extreme, and perhaps the most clearly relevant ones, this is a serious deficiency. The implication is that leaving out central alternatives in developing a multilevel model is not advisable, unless only extreme solutions are desired—not a likely situation at all.

In comparing Models 2A and 4, note that Model 4 is the same as Model 2A, except that in Model 4 the alternatives for each local planning unit with the high and low relative timber prices are not included. This exclusion results in increased suboptimality, but not nearly as much as was encountered in Model 3. This corroborates the earlier conclusions from comparing Models 3 and 4 and from comparing Models 2A and 2B.

Comparing Model 2B with Models 3 and 4 yields similar conclusions. If a model such as 2B is not feasible, then reduction in size along the lines of Model 4 appears to be safer than along the lines of Model 3. Retention of "middle" lower level alternatives and variation in local budget levels appear to be the most important factors in designing the configuration of the multilevel model, based on these tests.

The relatively good performance of Model 4 is encouraging, especially considering that the test case only involves two outputs and one time period. From a linear programming perspective, increasing the number of time periods and increasing the number of outputs are equivalent complications—for example, tracking timber over five time periods is modeled by simply defining five outputs: timber in time period one, timber in time period two, etc. Thus, in a practical planning situation, the number of outputs is likely to be much larger than two because of both a more complicated production system and the inclusion of different time paths of production (scheduling). As the number of outputs increases, the number of lower level land unit alternatives that would have to be generated increases dramatically for a multilevel model such as Models 1 through 3. For example, to emulate Models 2A and 2B that include three (two-output) price vectors for a case with 15 outputs (perhaps three outputs over five time periods) would require taking $3^{(15-1)}$ or 4.8 million price vectors in combination with each local budget level. Model 4, however, can be emulated with one price vector taken in combination with each local budget level, regardless of the number of outputs or time periods.

Cost Analysis on Partial Selections

As established earlier, each solution to each multilevel model presented in table 4 involves one "partial selection" of two lower level alternatives, for a single local planning unit. A natural concern would be that the cost estimate for that particular lower level land unit would be inaccurate (overestimated)—it is a linear interpolation between the costs associated with the two lower level alternatives (Hof et al. 1985). Thus, for a chosen set of these partial selections, the actual cost of the interpolated output vector was determined by rerunning the lower level model (minimizing cost with output levels constrained to the appropriate levels). Even if the interpolated cost is nearly correct, if the discrete alternatives were implicitly evaluated and approved by the local planning unit officials, then the partial selection may still be undesirable or infeasible for reasons not captured in the model.

Table 5 presents the results of the cost analysis on the selected partial selections. For each upper level linear program configuration (1, 2A, 2B, 3, 4), two solutions and their ancillary partial selections were selected—one with a partial selection close to an even 50–50 split and one with a partial selection close to an 80–20 split. The first column in table 5 indicates the model configuration that the partial selections came from. The second column indicates the local planning unit where the upper level model chose to make the partial selection. The third column indicates the two local alternatives (defined by local budget level and price set) that were partially selected. The fourth column indicates the percent of each alternative that was partially selected. The fifth column indicates the estimate of cost for the partial selection that was calculated (in the upper level model solution) as a linear interpolation between the two given alternatives' costs. The sixth column presents the actual minimum cost obtained by rerunning the lower level model with a cost minimization objective function and with timber and forage constrained to the levels implied by the partial selection. The last column indicates the percent error in the interpolated cost estimate, relative to the actual minimum cost.

All of the interpolated cost estimates are relatively accurate (within 4%), except for the two partial selections tested from the Model 3 configuration. This is not a surprising result, given that the Model 3 configuration specified only two (extreme) budget levels for each lower level model. This characteristic caused the Model 3 configuration to perform poorly from the viewpoint of global optimization, and also appears to cause it to perform poorly from a viewpoint of the accuracy of the interpolated cost estimate implied in a partial selection. Despite this, it is encouraging that with upper level model configurations that include variation in local budget levels, the cost estimate implied by a partial selection may not be terribly inaccurate. Pragmatic considerations may still make a partial selection unusable; but based strictly on the cost analysis in table 5, it may not be thoroughly untenable.

Table 5.—Cost analysis on certain partial selections from the upper level linear programming solutions.

Model	Local planning unit	Alternatives in Partial Selection		interpolated cost estimate	Actual minimum cost	Error in interpolated cost estimate
		Budget/Price set	Percent in solution			
				----------- dollars	-----------	percent
1	Oregon/National forest lands	4/4	85	333,679,987	323,891,044	3.02
		3/5	15			
		2/3	50	219,770,010	218,666,081	0.50
		3/3	50			
2A	Washington/National forest lands	3/3	87	99,280,024	97,614,012	1.71
		1/3	13			
		3/5	55	81,979,976	76,116,690	3.62
		1/5	45			
2B	Oregon/Other lands	3/3	89	302,479,996	299,427,812	1.02
		4/3	11			
		4/2	59	373,720,025	364,972,040	2.40
		3/2	41			
3	Oregon/National forest lands	4/1	73	287,469,036	259,139,480	10.93
		1/1	27			
		1/1	54	228,628,158	202,504,350	14.14
		4/1	46			
4	Oregon/National forest lands	1/3	87	142,469,000	138,589,650	2.80
		3/3	13			
		3/3	58	292,219,956	287,234,960	1.74
		4/3	42			

It was anticipated that the 80–20 partial selection cost estimates would be more accurate than the 50–50 counterparts, because the 80–20 ones are proportionately closer to a point with known cost. In table 5, this was not always the case. Comparing the two partial selections for the Model 1 configuration, for example, the cost error for the 85–15 partial selection is about six times that for the 50–50 partial selection. The apparent reason for this result is that the production function being modeled is not close to being homothetic, and does not exhibit constant returns to outlay. This would indicate that errors in interpolated cost estimates are not very systematic, and would be difficult to predict. Again, information concerning response to changing local budgets is very important. In the partial selections tested for Model configurations 2A, 2B, and 3, the budget codes involved in the partial selection for each local planning unit are the same, and as expected, the interpolated cost estimates for 80–20 partial selections are more accurate than for the 50–50 partial selections. In the partial selections tested for the Model 4 configuration, different budgets are involved, and the 80–20 partial selection cost estimate is, again, less accurate than the 50–50 counterpart.

Objective Function Test Results for Integer Programming Solution of the Upper Level Models

Table 6 presents a set of ratios similar to those in table 4, except that the numerators of these ratios are the objective function solution values arrived at through integer programming solution of the upper level model (so as to avoid the partial selection). The differences between these ratios and the equivalent ratios in table 4 are also given, in parentheses.

One simple but important conclusion can be derived from table 6. The only instance where a signficant loss in the objective function takes place because of avoiding the partial selection is in Integer Model 3, which did not perform particularly well in table 4 in the first place. Even for Model 3, the integer constraints never cause an increase in suboptimality (as measured here) of more than 5 percentage points. Otherwise, the integer solution approach does not significantly affect the conclusions drawn on table 4. The results in tables 4 and 6 are slightly conservative. Table 4 is slightly conservative because the interpolated cost estimates for the partial selection are always high. Table 6 is slightly conservative because the integer solutions yield a very small slack (never more than 0.5%) on the budget constraint.

Given the information in table 5, and the possibility that problems other than cost errors may be involved in trying to use the partial selections implied by the models in table 4, the integer solution approach seems to be supported in terms of overall suboptimality. Given the mixed integer model formulation discussed earlier, it also seems possible to solve relatively large upper level integer models with relatively few integer variables—so computational problems should not be terribly serious. However, the case example involves only one global constraint. In cases with more global constraints, the discrepancy between linear programming and integer

Table 6.—Ratios of objective function solution values of different upper level integer programming models to those of the global model. The numbers in parentheses are the differences between these ratios and the ratios in table 4.

Global budget constraint	Relative timber prices	Upper level integer programming model				
		1	2A	2B	3	4
High	High	0.9900 (.0008)	0.9885 (.0015)	0.9846 (.0023)	0.9816 (.0023)	0.9708 (.0015)
High	Medium	.9939 (.0003)	.9939 (.0003)	.9936 (.0006)	.9273 (.0003)	.9936 (.0006)
High	Low	.9924 (.0007)	.9883 (.0028)	.9883 (.0014)	.9656 (.0027)	.9711 (.0014)
Medium	High	.9916 (.0005)	.9872 (.0019)	.9863 (.0018)	.9056 (.0019)	.9546 (.0010)
Medium	Medium	.9966 (.0011)	.9894 (.0004)	.9894 (.0004)	.8608 (.0042)	.9894 (.0004)
Medium	Low	.9963 (.0000)	.9895 (.0023)	.9895 (.0030)	.9453 (.0045)	.9625 (.0008)
Low	High	.9589 (.0043)	.9477 (.0040)	.9422 (.0039)	.8981 (.0112)	.8941 (.0042)
Low	Medium	.9904 (.0018)	.9775 (.0051)	.9775 (.0051)	.8666 (.0184)	.9775 (.0051)
Low	Low	.9952 (.0008)	.9928 (.0000)	.9928 (.0008)	.8598 (.0465)	.9415 (.0000)

programming solutions may be larger. This point also applies to all subsequent comparisons between linear programming solutions and integer programming solutions.

Total Output Test Results

Tables 7 and 8 present ratios between total timber and forage output solution values for the different upper level models and the equivalent solution values from the global model. The integer programming ratios are given in parentheses under the linear programming ratios in both tables. With several exceptions (especially the case of forage with the low global budget constraint and the high relative timber price), the global model's output mix is approximated relatively closely by both the linear and integer programming upper level models. The approximation is generally best with the medium relative timber price. This is not surprising, because the high and low relative timber prices are quite extreme and would thus tend to stress the model results significantly. With the low global budget constraint and high relative timber prices, forage is essentially no more than a residual output, which explains the highly unstable results under those conditions. The model configuration appears generally to affect the output mix only slightly, although Models 3 and 4 exhibit some occasional instabilities, especially in forage output levels. Also, it is very difficult to say that the linear programming models perform any differently, in general, than the integer programming counterparts.

The results presented in tables 7 and 8 are based on a rather gross aggregation of regional outputs. Because the regional outputs were priced differently to represent the qualitative and other differences between regional outputs, aggregating them as in tables 7 and 8 is technically inappropriate. Nonetheless, tables 7 and 8 suggest that within a reasonable range of relative prices, the multilevel modeling approach should perform rather well in approximating the global output mix that would be arrived at if a single-level global optimization were possible. This conclusion is especially tenable with moderately constraining global budget constraints and with relative price vectors not too far from those used in developing the multilevel model alternatives. With the more extreme relative prices tested, the results are far less promising.

Regional Output and Cost Allocation Test Results

The results from Models 2A and 4 were chosen for presentation to indicate the reasonable range of regional and lower level output solution results. The Model 1 configuration, with 20 alternatives per local planning unit, is probably too "optimistic" for any situation that involves more than two outputs and one time period.

Tables 9 and 10 present ratios between regional timber and forage output solution values, respectively, for the linear and integer (in parentheses) versions of Models 2A and 4 and the equivalent solution values from the global model. The regional timber and forage outputs are significant principally because these are at the highest

Table 7.—Ratios of total timber solution values of different upper level linear (integer) programming models to those of the global model.

Global budget constraint	Relative timber prices	Upper level linear programming				
		1	2A	2B	3	4
High	High	0.9776 (.9895)	0.9899 (.9957)	0.9422 (.9328)	0.9715 (.9465)	0.9129 (.9259)
High	Medium	.9754 (.9885)	.9754 (.9885)	.9754 (.9889)	.9349 (.9341)	.9754 (.9889)
High	Low	.9916 (.9942)	.9482 (.9283)	1.0496 (1.0332)	.8894 (.9035)	1.1040 (1.0912)
Medium	High	.9708 (.9645)	.9777 (.9636)	.9139 (.9093)	.8975 (.9677)	.8383 (.8419)
Medium	Medium	.9978 (1.0306)	1.0027 (.9923)	1.0027 (.9923)	.9262 (.9049)	1.0027 (.9923)
Medium	Low	.9603 (.9657)	.9008 (.9254)	1.0265 (1.0054)	.8406 (.8124)	1.1088 (1.1130)
Low	High	.9783 (1.0139)	.9755 (.9855)	.8986 (.9142)	.9404 (.9437)	.8049 (.8205)
Low	Medium	1.0127 (1.0268)	1.0089 (1.0515)	1.0089 (1.0515)	1.0007 (1.0656)	1.0089 (1.0515)
Low	Low	.9873 (.9882)	.9341 (.9315)	1.0330 (1.0338)	.8580 (1.0389)	.8949 (.8949)

Table 8.—Ratios of total forage solution values of different upper level linear (integer) programming models to those of the global model.

Global budget constraint	Relative timber prices	Upper level linear programming				
		1	2A	2B	3	4
High	High	0.9642 (1.0189)	0.6074 (.7797)	1.8045 (1.5083)	0.5018 (.7797)	2.0045 (2.1008)
High	Medium	1.0006 (.9982)	1.0006 (.9982)	1.0006 (.9970)	.7375 (.7399)	1.0006 (.9970)
High	Low	.9907 (.9907)	1.0104 (1.0159)	.9649 (.9638)	1.0230 (1.0016)	.9248 (.9227)
Medium	High	.9742 (1.0204)	.4314 (.5739)	2.3944 (2.3877)	.4963 (.8656)	3.1418 (3.1750)
Medium	Medium	1.0178 (1.0271)	1.0357 (1.0338)	1.0357 (1.0338)	.7503 (.7927)	1.0357 (1.0338)
Medium	Low	1.0022 (.9995)	1.0157 (1.0147)	.9766 (.9718)	1.0071 (.9929)	.9240 (.9234)
Low	High	2.6687 (2.7358)	2.1025 (2.6137)	11.7926 (11.9777)	2.1589 (2.4527)	16.4095 (16.6242)
Low	Medium	.9897 (.9533)	.9994 (1.0073)	.9994 (1.0073)	.7949 (.8131)	.9994 (1.0073)
Low	Low	.9919 (.9951)	1.0038 (1.0032)	.9849 (.9838)	.9094 (.8512)	.8949 (.8949)

Table 9.—Ratios of regional timber output solution values in upper level linear (integer) programming Models 2A and 4 to those of the global model.[1]

Global budget constraint	Relative timber price	Model 2A			Model 4		
		Region 4	Region 5	Region 6	Region 4	Region 5	Region 6
High	High	0.9778 (1.0343)	0.7417 (.7417)	1.0304 (1.0185)	0.9084 (1.0044)	0.0925 (.0925)	1.0331 (1.0185)
High	Medium	.9259 (.9976)	.4927 (.4927)	1.0132 (1.0066)	.9259 (.9990)	.4927 (.4927)	1.0132 (1.0066)
High	Low	1.0224 (1.0403)	.5122 (.1867)	.9578 (.9487)	1.2520 (1.1771)	.3149 (.3149)	1.1167 (1.1216)
Medium	High	.8538 (.8045)	1.9292 (1.9292)	.9934 (.9934)	.6071 (.6354)	.1772 (0.0000)	.9584 (.9584)
Medium	Medium	1.1722 (1.1116)	1.1785 (1.1785)	.9442 (.9494)	1.1722 (1.1116)	1.1785 (1.1785)	.9442 (.9494)
Medium	Low	.8933 (1.0307)	.7401 (.7401)	.9084 (.8837)	1.1141 (1.1565)	1.2487 (1.2487)	1.1022 (1.0907)
Low	High	1.0405 (1.1236)	2.8935 (2.8935)	.8975 (.8829)	.7660 (.8737)	0.0000 (0.0000)	.8416 (.8263)
Low	Medium	1.1250 (1.4165)	∞ (∞)	.9309 (.8892)	1.1250 (1.4165)	∞ (∞)	.9309 (.8892)
Low	Low	.9173 (.9101)	∞ (∞)	.9145 (.9145)	1.1537 (1.1578)	∞ (∞)	1.1633 (1.1615)

[1] *The ∞ symbol indicates that no production of timber occurred in the global model solution for that region.*

Table 10.—Ratios of regional forage output solution values in upper level linear (integer) programming Models 2A and 4 to those of the global model.

Global budget constraint	Relative timber price	Model 2A			Model 4		
		Region 4	Region 5	Region 6	Region 4	Region 5	Region 6
High	High	0.7778 (1.1452)	0.07068 (.07068)	0.5591 (.4483)	1.3005 (1.4741)	5.6815 (5.6815)	1.4573 (1.4579)
High	Medium	.9922 (.9834)	1.0022 (1.0022)	1.0099 (1.0153)	.9922 (.9789)	1.0022 (1.0022)	1.0099 (1.0153)
High	Low	1.0029 (1.0030)	1.0011 (1.0014)	1.0420 (1.0663)	.9478 (.9416)	.9897 (.9897)	.7544 (.7541)
Medium	High	.9577 (1.3383)	.06742 (.06742)	.1309 (.1309)	2.5662 (2.7381)	9.9011 (9.6907)	1.6012 (1.6012)
Medium	Medium	1.0267 (1.0212)	.9985 (.9985)	1.1734 (1.1731)	1.0267 (1.0212)	.9985 (.9985)	1.1734 (1.1731)
Medium	Low	.9993 (.9983)	1.0001 (1.0001)	1.0706 (1.0681)	.9449 (.9442)	.9884 (.9884)	.7624 (.7628)
Low	High	11.0774 (14.1740)	.4235 (.4235)	.2660 (.2519)	29.6089 (30.7981)	60.8789 (60.8789)	5.8909 (5.9172)
Low	Medium	1.0365 (1.0769)	.9978 (.9978)	.9389 (.9156)	1.0365 (1.0769)	.9978 (.9978)	.9389 (.9156)
Low	Low	.9877 (.9863)	1.0025 (1.0025)	1.0283 (1.0283)	.9349 (.9353)	.9907 (.9907)	.6555 (.6548)

level of aggregation that is clearly tenable. And, the regional output reallocation implied by the multilevel solutions (relative to the global solution) is actually very similar to the local planning unit reallocations. In comparing the multilevel output solution values with the global output solution values, the local planning units within each region tend to "move together."

In studying tables 9 and 10, it is clear that definite instabilities occur in the multilevel solutions regarding regional output mixes. When the medium relative timber prices are used, the multilevel solution emulates the global solution rather closely. In other cases, however, the regional output levels arrived at by the multilevel models vary from their counterparts in the global model by factors as large as 60. Because, in developing the multilevel models, a price vector was used that was identical to the "medium" price vector used in these tests, it can be concluded that the multilevel model will only approximate the global optimal regional output levels with price vectors close to those used in developing the multilevel model. In tables 9 and 10, the results are most unstable with the extreme budget constraints taken in combination with the extreme relative timber prices; therefore, it appears that there is an interaction between these two factors. Model 2A does not perform much differently than Model 4 in tables 9 and 10. Even Model 1 does not perform much differently. For example, the Model 1 equivalents to the first rows in tables 9 and 10 are as follows.

	Region 4	Region 5	Region 6
Table 9	0.9473	0.74170	1.0228
Table 10	1.1566	0.07068	1.0576

Again, it does not seem to make very much difference whether the multilevel model is solved in a linear programming or integer programming format—each version performs slightly better sometimes and slightly worse other times. The basic conclusion appears to be that unless relative price vectors used in the upper level optimization are close to one of the price vectors used in building the upper level model, the multilevel solution regional outputs may be significantly different from the true global optimal figures. With anything other than a moderately constraining global budget constraint, this instability is potentially serious, even with the least stressing price vectors. It is important, however, that the multilevel model is capable of emulating the global model in at least the least stressing circumstances. In many planning problems, the price vectors that are to be used are known ahead of time, and only moderately constraining global budget constraints (relative to an unfettered maximization of net worth) are relevant.

Table 11 presents ratios between the regional budget allocations from the linear and integer (in parentheses) versions of Models 2A and 4 and the equivalent solution values from the global model. These are reported simply for comparison with the results in tables 9 and 10. The regional budget allocations in the multilevel models are somewhat closer to their counterparts in the global model than are the associated output results. Runset 2A and 4 perform more or less similarly, and, again, the integer programming solution only performs worse than the linear programming approach in a few cases. With the high relative timber prices, the budget allocations became more unstable in the multilevel model. Overall, the results in table 11 appear to have averaged out some of the more severe results in tables 9 and 10, but basically demonstrate similar problems in the multilevel models, especially with the more extreme price sets.

Local Planning Unit Output and Cost Allocation Test Results

Table 12 presents ratios between local planning unit timber and forage output solution values for upper level Models 2A and 4 and the equivalent solution values from the global model. Because the results in table 12 are from tests with the medium relative timber prices and the medium global budget constraint, they represent an optimistic situation. With medium relative timber prices and the medium global budget constraint, the solutions of Models 2A and 4 are identical. Even in this optimistic case, the multilevel models can indicate local level output solution values as much as 250% different from the global solution values. As before, the integer programming format generally does not yield results that are much different from the linear programming format. An important exception follows.

Most of the deviation between the global timber output solution values and those from the multilevel model solutions seems to be concentrated in one local planning unit—Oregon "other" lands. That is, the timber outputs on all other planning units are greater than those in the global model, whereas timber is "underproduced" on the Oregon "other" lands. With the integer programming solution, this also happens in the Wyoming NFS lands, and the overproduction on Wyoming "other" lands is exacerbated. It is clear that any solution to the multilevel model would have to be subject to some careful examination by the local level planners, and no solution should ever be taken as absolute. Such post-solution evaluation and adjustment would actually be required no matter what sort of analysis was undertaken.

Table 13 presents ratios of cost solution values for the same set of tests as in table 12. Again, even in this optimistic case (medium global budget constraint, medium relative timber prices), it would appear that the multilevel model may result in a budget allocation across local planning units that is significantly different from that which would be arrived at through a global model. Again, the "error" seems to be concentrated in much the same way that it was in table 12 for timber outputs. With the integer programming solution approach, the local budgets chosen are different in two local planning units besides the one where the partial selection occurred in the linear programming format. This results in a radically different budget for these local planning units, especially the Wyoming NFS planning unit. It would appear that the linear programming upper level model is significantly more stable than the integer programming approach in terms of local planning unit budget allocations. To a

Table 11.—Ratios of regional cost allocations in upper level linear (integer) programming Models 2A and 4 to those of the global model.

Global budget allocation	Relative timber price	Model 2A			Model 4		
		Region 4	Region 5	Region 6	Region 4	Region 5	Region 6
High	High	0.9325 (1.1600)	0.6890 (.6890)	1.0682 (1.0408)	1.0373 (1.2802)	0.4258 (.4258)	1.1061 (1.0773)
High	Medium	.9090 (.9929)	.8370 (.8370)	1.0381 (1.0263)	.9090 (.9853)	.8370 (.8370)	1.0374 (1.0263)
High	Low	1.1020 (1.1319)	.8442 (.6600)	1.0180 (1.0504)	1.0921 (.9895)	.6600 (.6600)	1.0576 (1.0662)
Medium	High	.8148 (.8132)	2.1999 (2.1999)	.9710 (.9710)	.7432 (.8093)	2.4124 (2.1999)	.9710 (.9710)
Medium	Medium	1.2051 (1.1529)	1.0206 (1.0206)	.9621 (.9704)	1.2051 (1.1529)	1.0206 (1.0206)	.9621 (.9704)
Medium	Low	.9363 (1.0875)	.9833 (.9833)	1.0203 (.9816)	.9300 (.9745)	.9833 (.9833)	1.0219 (1.0056)
Low	High	1.4230 (1.6958)	4.2740 (4.2740)	.8655 (.8428)	1.4230 (1.6869)	4.2740 (4.2740)	.8655 (.8428)
Low	Medium	1.1472 (1.4463)	1.1294 (1.1294)	.9305 (.8710)	1.1472 (1.4463)	1.1294 (1.1294)	.9304 (.8710)
Low	Low	.9339 (.9321)	1.1023 (1.1023)	.9858 (.9858)	.9272 (.9321)	1.1023 (1.1023)	.9882 (.9858)

Table 12.—Ratios of "local planning unit" output solution values occurring in both upper level Models 2A and 4 to those of the global model (medium global budget constraint and medium relative timber prices).

State	Ownership (NFS = National Forest System)	Upper level linear programming solution		Upper level integer programming solution	
		Timber	Forage	Timber	Forage
Idaho	NFS	1.1722	1.2285	1.1722	1.2285
	Other	1.0010	1.0000	1.0010	1.0000
Wyoming	NFS	1.2646	1.1770	.7445	.8199
	Other	2.7601	.9651	3.4869	.9756
Utah	NFS	1.0071	.9996	1.0071	.9996
	Other	1.3025	.9855	1.3025	.9855
Nevada	NFS	1.0000	1.0012	1.0000	1.0012
	Other	1.0000	1.0240	1.0000	1.0240
California	NFS	1.2032	.9940	1.2032	.9940
	Other	1.1341	.9996	1.1341	.9996
Oregon	NFS	1.0980	.9526	1.0980	.9526
	Other	.6333	1.1496	.6333	1.1496
Washington	NFS	1.0442[1]	0.9507[1]	1.0819	.9342
	Other	1.0120	1.3317	1.0120	1.3317

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[1] *Local planning unit where partial selection occurred in upper level linear programming solution.*

Table 13.—Ratios of local planning unit cost allocations in both upper level Models 2A and 4 to those in the global model and lower level budget code selected[1] (medium global budget constraint and medium relative timber prices).

State	Ownership (NFS = National Forest System)	Upper level linear programming solution		Upper level integer programming solution	
		Cost allocation	Selected budget	Cost allocation	Selected budget
Idaho	NFS	1.4276	3	1.4276	3
	Other	1.0005	3	1.0005	3
Wyoming	NFS	1.4326	3	.7163	1
	Other	1.3745	3	1.6920	4
Utah	NFS	1.0069	1	1.0069	1
	Other	1.0628	3	1.0628	3
Nevada	NFS	1.0044	3	1.0044	3
	Other	1.0883	3	1.0883	3
California	NFS	1.0641	3	1.0641	3
	Other	1.0077	3	1.0077	3
Oregon	NFS	1.1561	3	1.1561	3
	Other	.6019	1	.6019	1
Washington	NFS	1.1198	.13(1) + .87(3)	1.1956	3
	Other	1.0716	3	1.0716	3

[1] *The lower level price code 3 was selected for all local planning units, in all solutions with the medium global budget constraint and medium relative timber prices.*

Table 14.—Ratios of a selected local planning unit (Idaho National Forest System) output and cost solution values in upper level linear (integer) programming Models 2A and 4 to those of the global model.

Global budget constraint	Relative timber price	Model 2A			Model 4		
		Timber	Forage	Cost (budget)	Timber	Forage	Cost (budget)
High	High	0.9576 (.9576)	0.2169 (.2169)	0.8750 (.8750)	0.8772 (1.0513)	2.0877 (2.1371)	0.8750 (1.3111)
High	Medium	.8955 (.8955)	.9771 (.9771)	.8057 (.8057)	.8955 (.8955)	.9771 (.9771)	.8057 (.8057)
High	Low	1.0369 (1.0369)	1.0268 (1.0268)	1.2210 (1.2210)	1.1912 (.9940)	.8803 (.8599)	1.2210 (.8149)
Medium	High	.8378 (.7376)	.4277 (.2876)	.7141 (.5299)	.6756 (.6756)	4.1356 (4.1356)	.5299 (.5299)
Medium	Medium	1.1722 (1.1722)	1.2285 (1.2285)	1.4276 (1.4276)	1.1722 (1.1722)	1.2285 (1.2285)	1.4276 (1.4276)
Medium	Low	.8744 (1.0483)	.9984 (1.0286)	.8327 (1.2476)	1.0049 (1.0049)	.8614 (.8614)	.8327 (.8327)
Low	High	.9074 (.9074)	.7279 (.7279)	.8443 (.8443)	.8311 (.8311)	10.4659 (10.4659)	.8443 (.8443)
Low	Medium	1.0722 (1.4920)	1.0570 (1.6987)	1.1291 (2.2582)	1.0722 (1.4920)	1.0570 (1.6987)	1.1291 (2.2582)
Low	Low	.9797 (1.0782)	.9897 (1.0295)	1.0209 (1.1432)	1.2391 (1.2391)	.8882 (.8882)	1.1432 (1.1432)

lesser degree, this also shows up in table 12. This sort of instability is somewhat discouraging and again points to the need for careful interpretation of the multilevel model solutions at the local level. Because the global solution generally would not be known, this evaluation admittedly would be subjective and unreliable —especially if the standard of comparison tended to be local optima, which may have no direct relationship with the global optima.

Tables 12 and 13 indicate the potential instabilities that could occur in even a relatively optimistic situation. To indicate a more complete picture of the potential local planning unit instabilities, table 14 presents the solution value ratios for outputs and costs with all nine budget and price vector combinations, for a selected (representative) local planning unit. The solution values for the given local planning unit from the multilevel model differ from the global solution values by as much as a factor of 10. The local solution values in the multilevel model also appear to be particularly unstable when the extreme relative timber prices are taken in combination with one of the more extreme global budget constraints.

Conclusions

The (Bartlett-Wong) multilevel modeling approach tested here does not appear to closely emulate a global optimization in terms of local level output solution values or budget allocations across local planning units. Regional output solution values are closely approximated only in the more optimistic cases. Yet, with moderate relative prices, the multilevel model comes very close to the global model in terms of total output solution values and, especially, in terms of overall optimality. In the tests discussed, the objective functions were a variety of weighted summations of outputs; therefore, stating that optimality is closely approximated implies that the multilevel model is able to locate "points" that are close to the true production possibilities frontier implied in the global model.

The only obvious way to interpret these results is that there are, in the global model tested, many ways to alter local level solutions that do not significantly affect global optimality (as measured by the given objective function). This implies that the multilevel model may be tenable in analyzing national production possibilities, but may lead to local level resource allocations that are not truly efficient relative to the local resource allocations that would result from a single-level global optimization. It is apparent that the multilevel optimization approach tested here could lead to undiscovered resource misallocations at the lower levels of the given planning system. Again, the multilevel approach is only suggested for cases where a single-level global optimization is not pragmatically possible.

Given these conclusions, and the fact that optimization problems that cannot be handled with a single, global model are likely to persist, it would appear that renewable resource agencies might consider developing the capability to pursue the Kornai and Liptak (1965) approach. The Bartlett-Wong approach evaluated here shows impressive capabilities at the highest level of the model; but because the allocations to lower levels seem to be suspect, it is not a universal solution. To employ a model along the lines suggested by Kornai and Liptak, the agency involved would need to have all lower level models operational during the same period of time, and communication channels would have to be opened to support the iterations between higher and lower levels. Until then, the Bartlett-Wong approach seems to have the potential to reliably address at least part of the problem, and encourages the general sorts of lower level models and communication lines that would be necessary for the Kornai and Liptak approach.

In applying the Bartlett-Wong approach, the findings in this report would suggest first, that the integer programming approach appears to perform very nearly as well as the linear programming approach (in the upper level model) in terms of approximating global optima. Because it treats lower level alternatives discretely, it is more reliable. An approach has been presented that allows solution of relatively large integer programs; but if a great many alternatives are included, an integer solution approach may not be possible. In this case, the linear programming approach to the upper level model appears to be a reasonable alternative.

Second, it is important to the performance of the Bartlett-Wong approach that the local planning units develop alternatives with prices and other variables (that are not used in global constraints) as close as possible to those that will eventually be used in the upper level model. This means that the direction of local planning analyses would not be toward defining the absolute limits of production or toward generating the widest possible range of alternatives. Instead, it would mean that the more information the national planning authority can provide to the local planners ahead of time, the more the local alternatives could focus on the relevant range of alternatives, and the more effective the Bartlett-Wong approach would be.

Third, if one purpose of local planning efforts is to support an analysis such as the Bartlett-Wong model, then the results reported here suggest that systematic variation in the implied budget requirements across local alternatives is more important than determining a variety of output sets on a given production frontier. This conclusion almost certainly results from the fact that the test case was formulated to address the problem of allocating a global budget to local planning units. If a different input or output constraint (or group thereof) is common to the local planning units, then parallel conclusions are likely to be drawn. If local planning units do not generate alternatives in a systematic manner, then there is no guarantee that the needed variation in the key variables will exist in the resultant alternatives. With this variation in key variables, the Bartlett-Wong approach appears to perform well (at the national level), even with a rather limited number of alternatives for each local planning unit.

Literature Cited

Ashton, P. G., J. B. Pickens, C. Ohlander, and B. Benninghoff. 1980. Many resources, many uses: A system analysis approach to renewable resource development. Water Resources Bulletin 16:738–744.

Bartlett, E. T. 1974. A desision-aiding model for planning optimal resource allocation of water basins. Ph.D. dissertation, 132 p. University of Arizona, Tucson.

Dantzig, G. B., and P. Wolfe. 1961. The decomposition algorithm for linear programs. Econometrica 29: 767–778.

Dantzig, G. B. 1963. Linear programming and extensions. 627 p. Princeton University Press, Princeton, N. J.

D'Aquino, S. A. 1974. Optimum allocation of resources: A programming approach. Journal of Range Management 27:228–233.

Hof, J. G., R. K. Marose, and D. A. King. 1985. Potential pitfalls in renewable resource decision making that utilizes convex combinations of discrete alternatives. Western Journal of Agricultural Economics 10:391–400.

Kornai, J., and T. Liptak. 1965. Two-level planning. Econometrica 33:141–169.

Kornai, J. 1975. Mathematical planning of structural decisions. 644 p. American Elsevier Publishing Company, New York, N. Y.

Kuchler, A. W. 1965. Potential natural vegetation of the coterminous United States (manual and map). American Geographic Society Special Publication 36(Rev.), 116 p., New York..

Silberberg, E. 1978. The structure of economics: A mathematical analysis. 543 p. McGraw-Hill, New York, N. Y.

USDA Forest Service. 1980. A recommended renewable resources program—1980 update. U.S. Department of Agriculture, Forest Service Report FS–316, 540 p. Washington, D.C.

Wong, C. P. 1980. A multilevel approach to the forest service planning process. M.S. thesis. Colorado State University, Fort Collins.

Appendix 1

Detailed Description of Global Model (NIMRUM)

The land classification system used in NIMRUM was based on Kuchler's (1965) Potential Natural Vegetation scheme with the addition of one vegetation type that Kuchler did not include. This type, "mountain meadows," was included because of its large impact on western range production. To avoid confusion, the land classifications were renamed "potential natural communities" (PNC). Within each PNC, the land base was separated by ownership, productivity class, and condition class designations (table A1). Each of these designations had four possible classifications, giving a total of 64 possible resource units (RU) for each PNC. The RU was the basic land management unit for the NIMRUM model. These RU's are analagous to the TYPE I and II lands in table 1. Outputs and costs per acre were assumed to be the same for an RU independent of where the specific land parcel was located.

The management options for each RU were defined as a combination of practices seeking a specific level of management (ML) for each of three output groups. The output groups were timber, range, and wildlife. Timber has six possible ML's (1 to 6), range has five possible ML's (A to E), and wildlife has three possible ML's (1 to 3). The definition of each of these levels is briefly presented in table A2. A combination of three ML's was called a management triplet. A subset of the 73 possible management triplets was selected by the interdisciplinary teams for each RU. E level range management excludes, by definition, any active management for the other outputs. In general, the ML triplets were selected for each PNC and then for each RU. Thus, RU's within a PNC had the same options or a subset of the options chosen for that PNC. Most PNC's had about 10 management triplets specified.

After the management level triplets had been selected, specific practices were selected for each RU to attain each desired management triplet. The management triplets were simply used to organize management op-

Table A1.—Land classification system within a PNC.

Ownership		
Code	**Ownership**	
1	National Forest System	
2	Natural Resource Lands (BLM)	
3	Other Federal	
4	Non-Federal	
Productivity Class		
Code	**Forested PNC's**	**Non-Forested PNC's**
1	120 + ft.^{3}/ac./yr.	High
2	85-110 ft.^{3}/ac./yr.	Moderately High
3	50-84 ft.^{3}/ac./yr.	Moderately Low
4	0-49 ft.^{3}/ac./yr.	Low
Condition Class		
Code	**Forested**	**Non-Forested**
1	Non-stocked	Good
2	Seedlings and Saplings	Fair
3	Poles	Poor
4	Sawtimber	Very Poor

Table A2.—Management level designations.

Range Management Level

A - Environmental management without livestock
B - Environmental management with livestock
C - Extensive management of environment and livestock
D - Intensive management of environment and livestock
E - Maximum management of environment and livestock

Timber Management Level

1 - No commercial use
2 - Minimal management (high-grading)
3 - Harvest and assure regeneration
4 - Harvest, assure regeneration, and commercial thin
5 - Harvest, assure proper stocking, and competition removal
6 - Harvest, assure proper stocking and competition removal, and fertilizing, and/or tree improvement

Wildlife Management Level

1 - No management
2 - Vegetation manipulation
3 - Vegetation manipulation and placement of structures

tions; these designations are somewhat artificial because of the jointness of the renewable resource production system. That is, practices designated for one output type actually affect the production of other outputs. The practices allowed are presented in table A3 by output classes.

After each management triplet was defined by specific practices, the interdisciplinary team predicted the quantity of outputs that would be expected. These formed the columns of the linear programming A-matrix (analagous to table 1). There were 13 outputs in NIMRUM; but only two outputs were included in this study—cubic feet of wood harvested and animal unit months of domestic forage grazing.

The NIMRUM model does not address scheduling problems directly. Information was collected on the amount of time that an RU with a given management triplet would be in specified condition classes. The practices and outputs data originally generated were the average levels over the condition classes. A program was written to convert the production and cost information from average per year for the condition classes into averages based on a 50-year planning horizon. A particular 50-year schedule is assumed for each management triplet in each RU. Thus, NIMRUM is an average-year static model. This planning horizon was chosen because the legislative mandate for RPA specifies a 50-year planning period.

Table A3.—Management practices by target output group.

	Units/100 M acres
Range Management Practice	
Fertilization	M acres
Irrigation	M acres
Water control	M acres
Mechanical vegetation control (low cost)	M acres
Mechanical vegetation control (high cost)	M acres
Vegetation manipulation - chemical	M acres
Vegetation manipulation - biological	M acres
Vegetation manipulation - fire	M acres
Debris disposal	M acres
Mechanical soil treatment	M acres
Seeding	M acres
Rodent control	M acres
Insect and disease control	M acres
Small water development	Sites
Large water development	Sites
Fence	Miles
Timber thinning	M acres
Timber Management Practice	
Planting	M acres
Direct seeding	M acres
Site prep. for natural regeneration	M acres
Site prep. for planting and seeding	M acres
Animal control for reforestation	M acres
Animal control for timber stand improvement	M acres
Precommercial thin	M acres
Release and weeding	M acres
Fertilization of established stands	M acres
Seed production areas	M acres
Selection and care of superior trees	M acres
Prescribed burning to control understory	M acres
Access roads for timber production	Miles
Cutting method-shelterwood and seed tree	M acres
Cutting method-salvage	M acres
Cutting method-clearcutting	M acres
Cutting method-commercial thinning	M acres
Cutting method-selection	M acres
Cutting method-selective	M acres
Wildlife Management Practice	
Water developments - upland	Sites
Seeding and planting	M acres
Liming and fertilizing	M acres
Fencing	Miles
Prescribed burning - uplands	M acres
Clearing	M acres
Brush and shrub management-mechanical	M acres
Brush and shrub management-chemical	M acres
Brush and shrub management-biological	M acres
Pruning	M acres
Thinning - release	M acres
Mechanical soil treatment	M acres
Dens and nest structures	Structures
Perch and nest structures	Structures
Brushpiles and covers	Brushpiles
Streambank stabilizers	Sites

Appendix 2

Mathematical Description of the Test Case Models

The only pervasive difference among models is the portion and level of aggregation of the land base used. The objective function for all three models is the same, to maximize weighted outputs. The production constraints are analogous and are only used to transfer outputs to the objective function. The inputs, budget and land, are analogous in all three models.

The superscript asterisk indicates that upper level model land unit definitions are being used. Absence of the superscripted asterisk indicates that lower level model land definitions are used. For example, the subscript i identifies specific resource units in one of the local planning unit models. In contrast, i* represents the land base for one of the local planning units.

The algebraic representations along with definitions for subscripts and variables is:

Upper Level Model Algebraic Formulation

$$\text{Maximize:} \quad \sum_{k=4}^{6} \sum_{p=1}^{2} W_{kp} \quad T_{kp} \quad \text{(Objective function)}$$

$$\text{Subject to:} \quad \sum_{i^*=1}^{I^*_k} \sum_{j^*=1}^{J^*} P_{i^*j^*p} \quad X_{i^*j^*} - T_{kp} = 0 \ \forall k, p$$

(Production accounting rows)

$$\sum_{k=4}^{6} \sum_{i^*=1}^{I^*_k} \sum_{j^*=1}^{J^*} C_{i^*j^*} \quad X_{i^*j^*} \leq B$$

(Budget constraint)

$$\sum_{j^*=1}^{J^*} X_{i^*j^*} = 1 \ \forall i^* \quad \text{(Unity constraints)}$$

Lower Level Model Algebraic Formulation

$$\text{Maximize:} \quad \sum_{p=1}^{2} W_{kp} \quad T_{kp} \quad \text{(Objective function)}$$

$$\text{Subject to:} \quad \sum_{i=1}^{I_{i^*}} \sum_{j=1}^{J_{ii^*}} P_{ijp} \quad X_{ij} - T_{kp} = 0 \ \forall p$$

(Production accounting rows)

$$\sum_{i=1}^{I_{i^*}} \sum_{j=1}^{J_{ii^*}} C_{ij} \, X_{ij} \leq B_{i^*} \text{(Budget constraint)}$$

$$\sum_{j=1}^{J_{ii^*}} X_{ij} = L_i \ \forall i \quad \text{(Land area constraints)}$$

Global Model Algebraic Formulation

$$\text{Maximize:} \quad \sum_{k=4}^{6} \sum_{p=1}^{2} W_{kp} \quad T_{kp} \quad \text{(Objective function)}$$

$$\text{Subject to:} \quad \sum_{i^*=1}^{I^*_k} \sum_{i=1}^{I_{i^*}} \sum_{j^*=1}^{J_{ii^*}} P_{ijp} \, X_{iji^*k} - T_{kp} = 0 \ \forall k, p$$

(Production accounting rows)

$$\sum_{i^*=1}^{I^*_k} \sum_{i=1}^{I_{i^*}} \sum_{j=1}^{J_{ii^*}} C_{ij} \, X_{iji^*k} \leq B$$

(Budget constraint)

$$\sum_{j=1}^{J_{ii^*}} X_{iji^*k} = L_{ii^*k} \ \forall i, i^*$$

(Land area constraints)

Definition of Variables

Subscripts

i	Represents the resource units (unique land types) for the lower level models.
i*	Represents the relevant lower level models for the kth region.
j	Represents the options for management of each resource unit.
j*	Represents the solutions within each lower level model.
k	Represents the Forest Service region, k=4, 5, or 6.
p	Represents the products considered by the model—wood harvest and domestic AUM production.

Variables

B = The amount of budget available.

B_{i^*} = The budget allocation for the i*th lower level model.

C_{ij} = The cost of managing 1 acre of resource unit i under management level j.

$C_{i^*j^*}$ = The cost for managing all of the lower level model i* under lower level solution j*.

I_{i^*} = The number of resource units in lower level model i*.

I^*_k = The number of lower level models in the k^th^ region.

J_{ii^*} = The number of management levels available for land unit i in lower level model i*.

J^* = The number of lower level solutions for each lower level model.

L_i = The total number of acres of resource unit i.

L_{ii^*k} = The number of acres available in resource unit i of lower level model i* and region k.

P_{ijp} = The output of product p from resource unit i managed in management level j.

$P_{i^*j^*p}$ = The output of product p from local planning unit i* under management j*.

T_{kp} = A variable to transfer the output from region k for product p from the production accounting rows to the objective function.

W_{kp} = The weight associated with a unit of product p produced in region k. These weights can be viewed as relative prices.

X_{ij} = The number of acres of resource unit i in managment level j chosen by the model.

$X_{i^*j^*}$ = The proportion of the land base for lower level planning unit i* that is allocated to lower level solution j*.

X_{iji^*k} = The number of acres in the global model that were selected for management level j from resource unit i in lower level model i* of region k.

Hof, John G., and James B. Pickens. 1986. A multilevel optimization system for large-scale renewable resource planning. USDA Forest Service General Technical Report RM–130, 23 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

This report analyzes and evaluates one approach to utilizing local planning analyses of public renewable resource management agencies as an input in developing large-scale (national) resource management plans. A type of multilevel approach (referred to as the Bartlett-Wong approach) is discussed, and is evaluated in a test case. This prototype performed well at the highest level of analysis but was less reliable in terms of its implications for the lower level planning units.

Keywords: Land management planning, forest economics, linear programming, integer programming.

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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